BENCHMARK WORKSHOP FOR BARENTS SEA AND FAROESE STOCKS (WKBARFAR 2021)

VOLUME 3 | ISSUE 21

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
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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

ISSN number: 2618-1371

ICES Scientific Reports

Volume 3 | Issue 21

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Recommended format for purpose of citation:

ICES. 2021. Benchmark Workshop for Barents Sea and Faroese Stocks (WKBARFAR 2021).
ICES Scientific Reports. 3:21. 205 pp. https://doi.org/10.17895/ices.pub.7920

Editors

Daniel Howell

Authors

Asgeir Aglen • Erik Berg • Matthias Bernreuther • Bjarte Bogstad • Olav Nikolai Breivik • Anatoly Chetyrkin • Gjert Endre Dingsør • Elise Eidset • Johanna Fall • Harald Gjøsæter • Torild Johansen • Knut Korsbrekke • Yuri Kovalev • Anders Nielsen • Kjell Nedreaas • Lise Ofstad • Kotaro Ono • Alfonso Perez Rodriguez • Yves Reecht • Alexey Russkikh • Silje Seim • Petur Steingrund • Dmitri Vasilyev • Natalia Yaragina

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i Executive summary

WKBARFAR 2021 met online to revise the advice basis of three stocks: Northeast Arctic (NEA) cod, Norwegian coastal cod north of 62 degrees, and Faroese ling. During the course of the meeting, it was decided to split the Norwegian coastal cod into two separate stocks: a data-rich stock north of 67 degrees north, and a data-poor stock between 62 and 67 degrees north. The NEA cod received a revision to the existing Category 1 SAM (State-space Assessment Model) model, Norwegian coastal cod south will receive advice based on the "3-over-2" rule, while both Norwegian coastal cod north and Faroese ling move from Category 3 to Category 1 stocks with SAM assessments.

NEA cod: A revised version of the Category 1 SAM assessment was approved for the advice basis for NEA cod. Given the use of density-dependence in estimating reference points, the benchmark was not able to revise these estimates. Tests were conducted indicating the biomass limit (B_{lim}) remained appropriate, that the existing Harvest Control Rule (HCR) remained precautionary, and that the performance of the HCR is not expected to be substantially impacted by the revision in the assessment model. Reference points will be fully re-evaluated at a forthcoming HCR evaluation, likely in 2022.

Faroese Ling: This stock will now be assessed with a Category 1 SAM model, previously the stock was Category 3 with no analytic assessment. Full reference points are estimated, although the actual management is currently based on days at sea controls.

Norwegian coastal cod north of 67°N: Category 1 SAM model, the first accepted analytic assessment for this stock. Evaluation of the Spawning–stock biomass (SSB) to recruit plot indicated a continued increase in recruitment across the range of SSBs observed during the model period. Consequently, B_{lim} is provisionally set to the highest observed SSB, with a strong recommendation to conduct further investigations and put in place a recovery plan for this stock. Without evidence of recruitment performance above B_{lim}, no reliable estimates could be provided for F reference points.

Norwegian coastal cod between 62 and 67°N: Advice for this stock will be using Category 3, with a "3-over-2" rule based on the Catch Per Unit of Effort (CPUE) index from the reference fleet, with a Length-Based Spawners Per Recruit (LBSPR) model used to indicate if a precautionary buffer is required. It is likely that a SPiCT (Production model in Continuous Time) model may be a viable future assessment method, once the reference fleet CPUE time-series has been extended sufficiently.

ii Expert group information

Expert group name	Benchmark Workshop for Barents Sea and Faroese Stocks (WKBarFar 2021)
Expert group cycle	Annual
Year cycle started	2020
Reporting year in cycle	1/1
Chair	Daniel Howell, Norway
Meeting venues and dates	Data Evaluation meeting 30 November –4 December 2020, Online (26 participants)
	Benchmark meeting 1–5 February 2021, Online (30 participants)

1 Introduction

WKBARFAR aimed to benchmark three different stocks, Faroese ling, NEA cod, and Norwegian coastal cod north of 62°. Of these, both coastal cod and ling had no previous ICES approved analytical assessment, while NEA cod was assessed with a SAM model. However, the NEA cod SAM model was approved at an inter-benchmark, and this is the first full benchmark for this assessment model.

The benchmark was run as a web-based meeting, with a preliminary one-day meeting one week previously. This pre-meeting presented the status and key issues for the work with each stock, and served to structure the benchmark and minimize the drawbacks associated with the online nature of the review.

2 Cod (*Gadus morhua*) in subareas 1 and 2 (Northeast Arctic) (Cod.27.1–2)

2.1 Why a benchmark?

The previous regular benchmark for this stock was held 2015 (ICES, 2015). At an Inter-benchmark in 2017, the SAM model was accepted as the main assessment model for this stock (ICES, 2017). *Ad hoc* changes in SAM settings were suggested by AFWG 2019 (ICES, 2019), but not accepted by ACOM. Thus, another benchmark was timely. Among the known issues were the retro pattern, and that the existing model settings gave very uncertain estimates of the plus group.

2.2 Summary of final model (assessment and prediction) and reference point investigations

2.2.1 SAM model

The final SAM model was based on the updated dataset (2.3.1 below) and the analysis carried out during the meeting (2.3.2).

The retro pattern is shown in Figures 2.1a–d and is relatively good, and better than that shown in the AFWG 2020 assessment (ICES, 2020a).

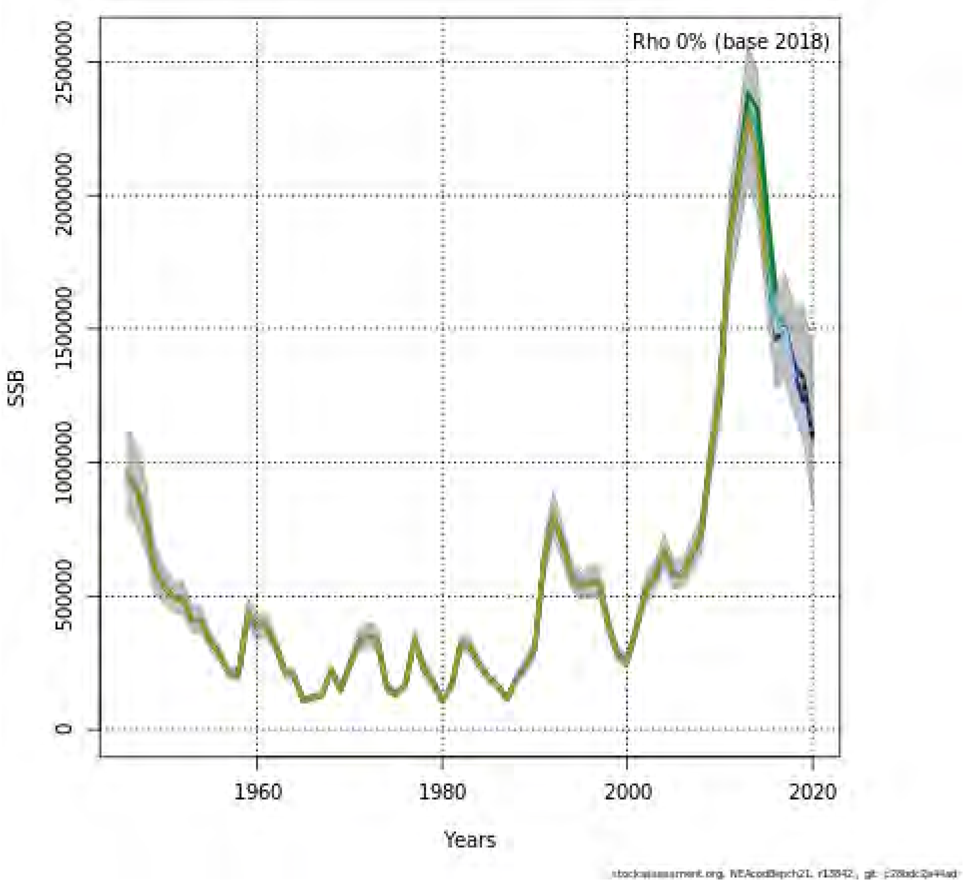


Figure 2.1a. Retrospective pattern (seven-year peel) of SSB of final model.

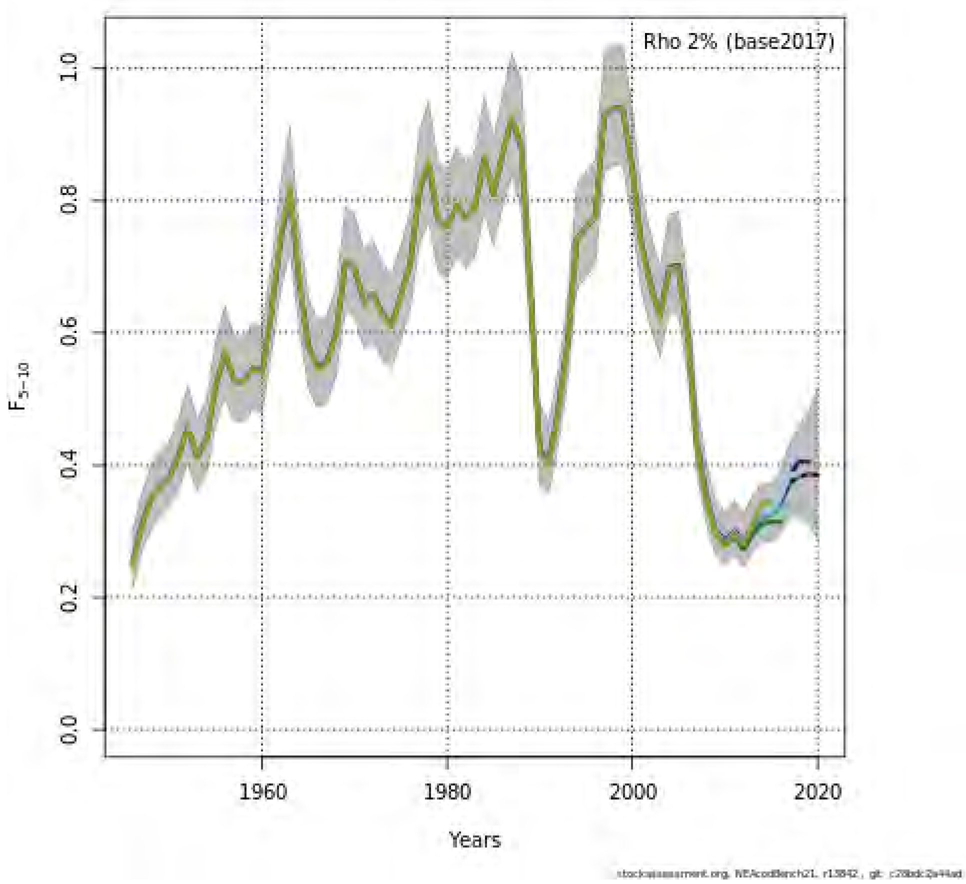


Figure 2.1b. Retrospective pattern (seven-year peel) of F_{bar} of final model.

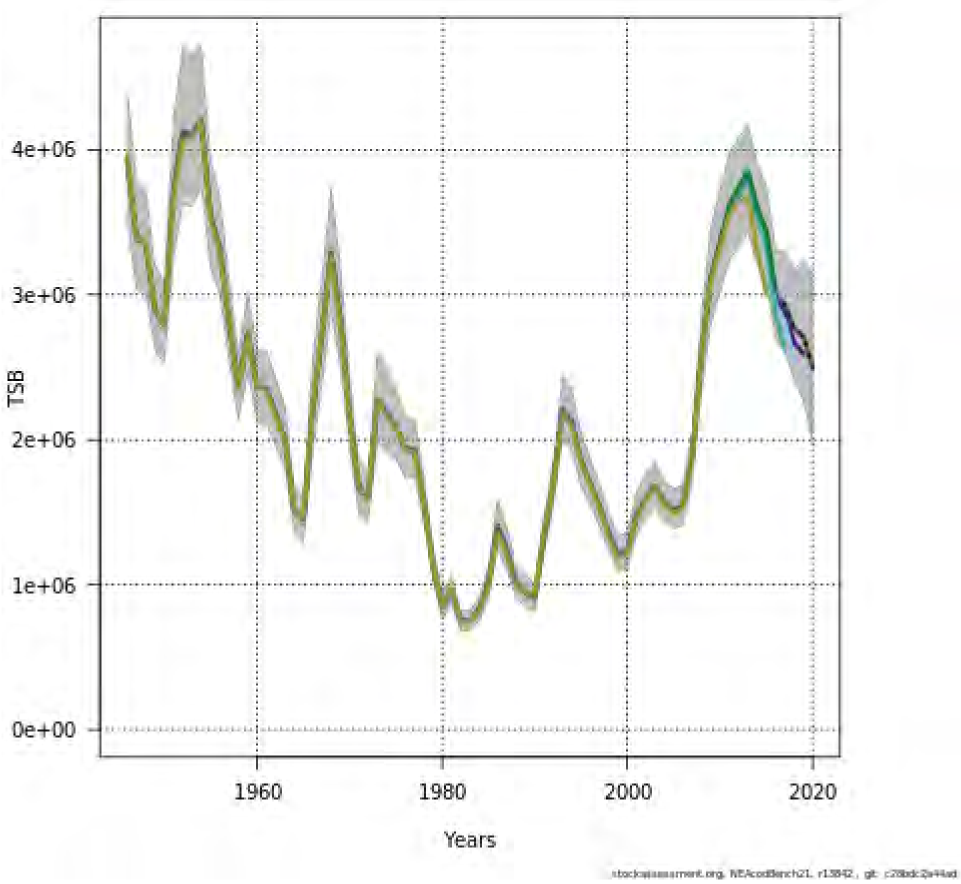


Figure 2.1c. Retrospective pattern (seven-year peel) of TSB of final model.

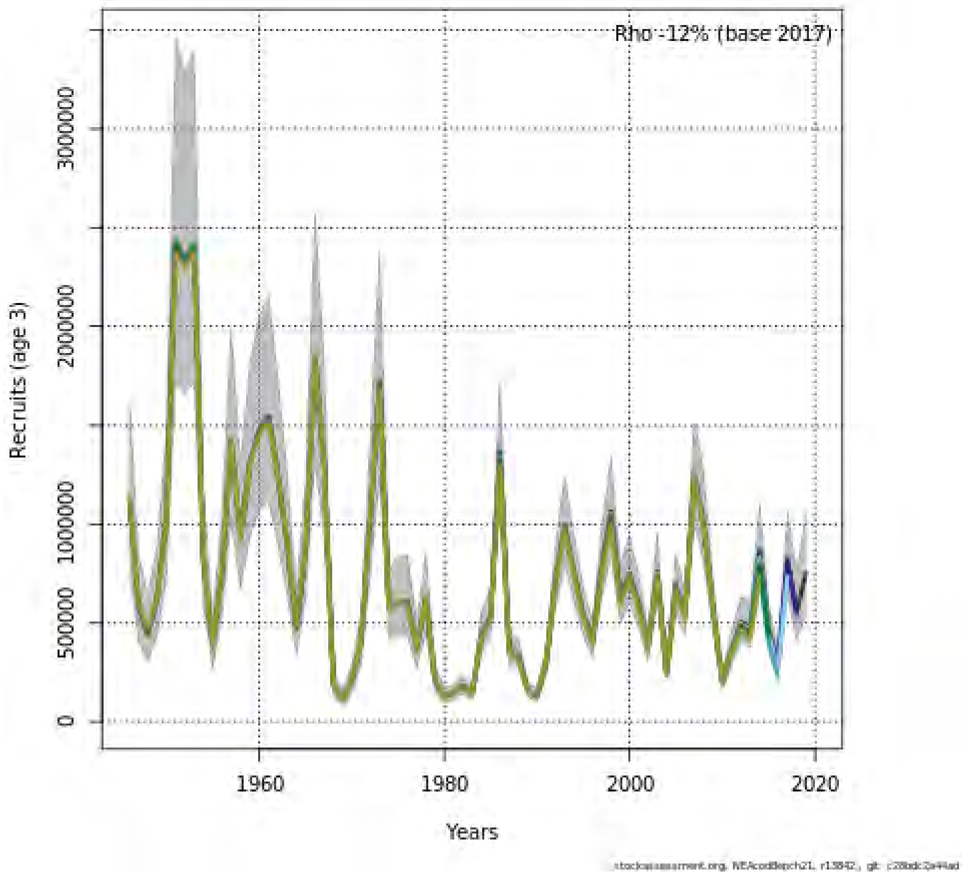


Figure 2.1d. Retrospective pattern (seven-year peel) of recruitment of final model.

The model now predicts the catches well (Figure 2.2), except for some years with very high catches, and also the very low catch in 1990. The latter is related to the strong reduction in catch levels from 1989 to 1990 when also strong restrictions on the Norwegian coastal fishery were introduced.

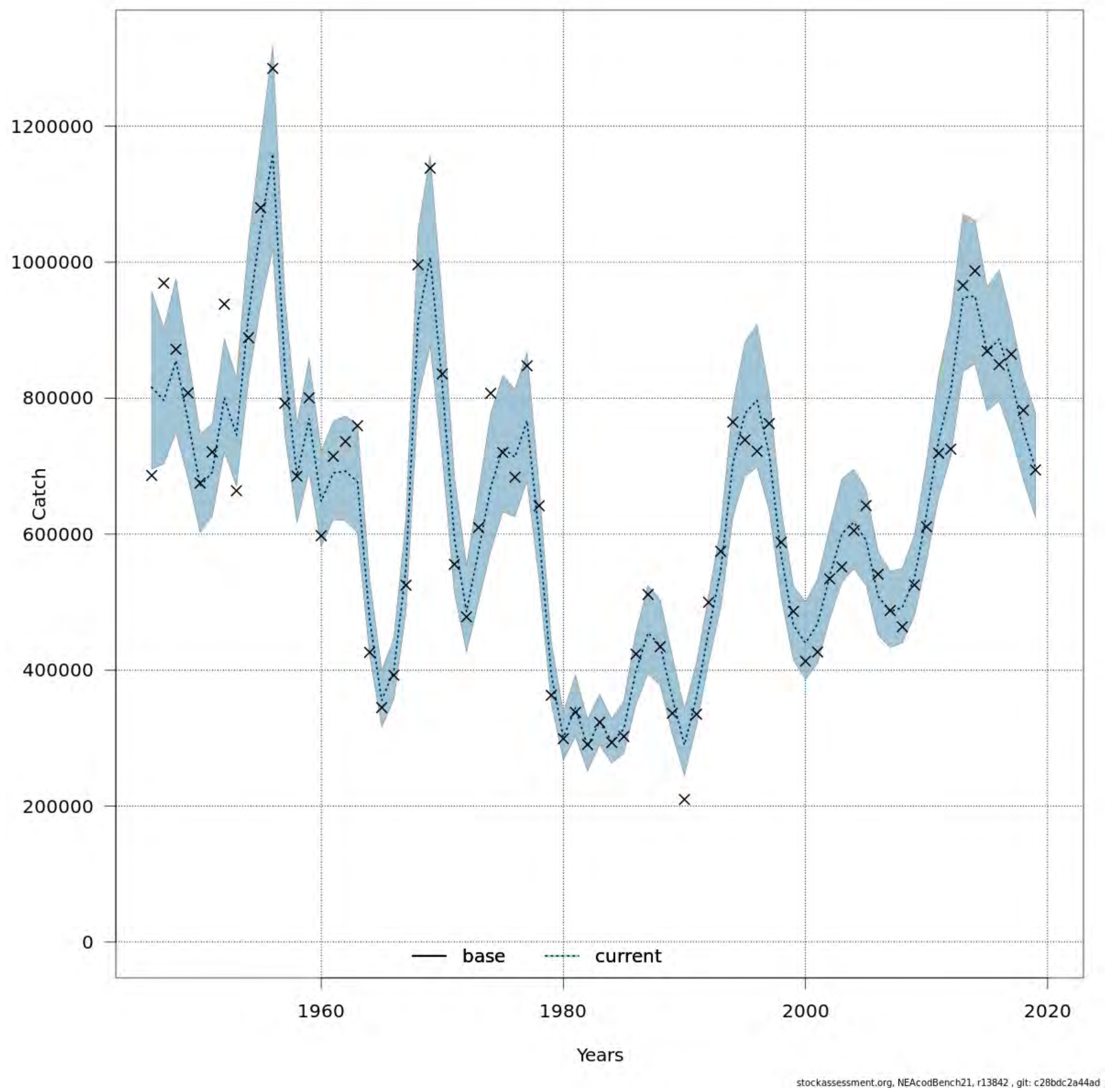


Figure 2.2. Observed (dotted) vs fitted catches (x).

The one-step-ahead (OSA) residuals or process errors did not show any obvious patterns (Figure 2.3). The leave one out diagnostics show that the model is strongly driven by the catch data (Figure 2.4).

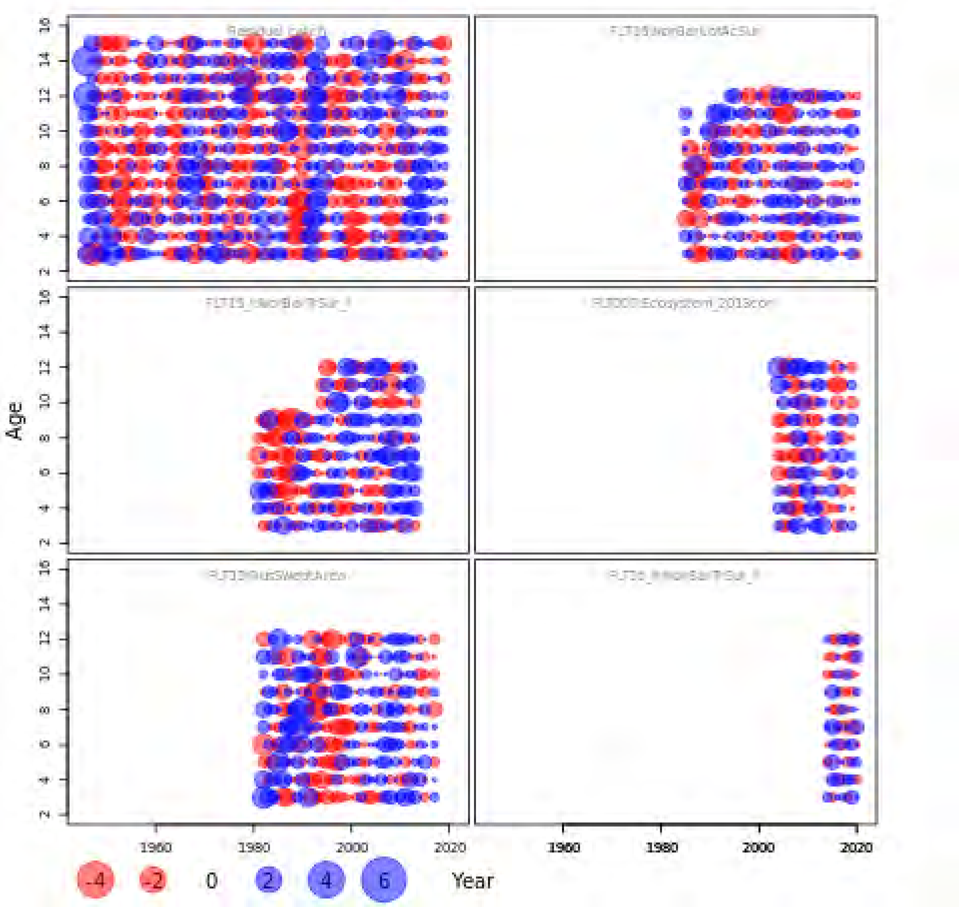


Figure 2.3a. OSA residuals from final model.

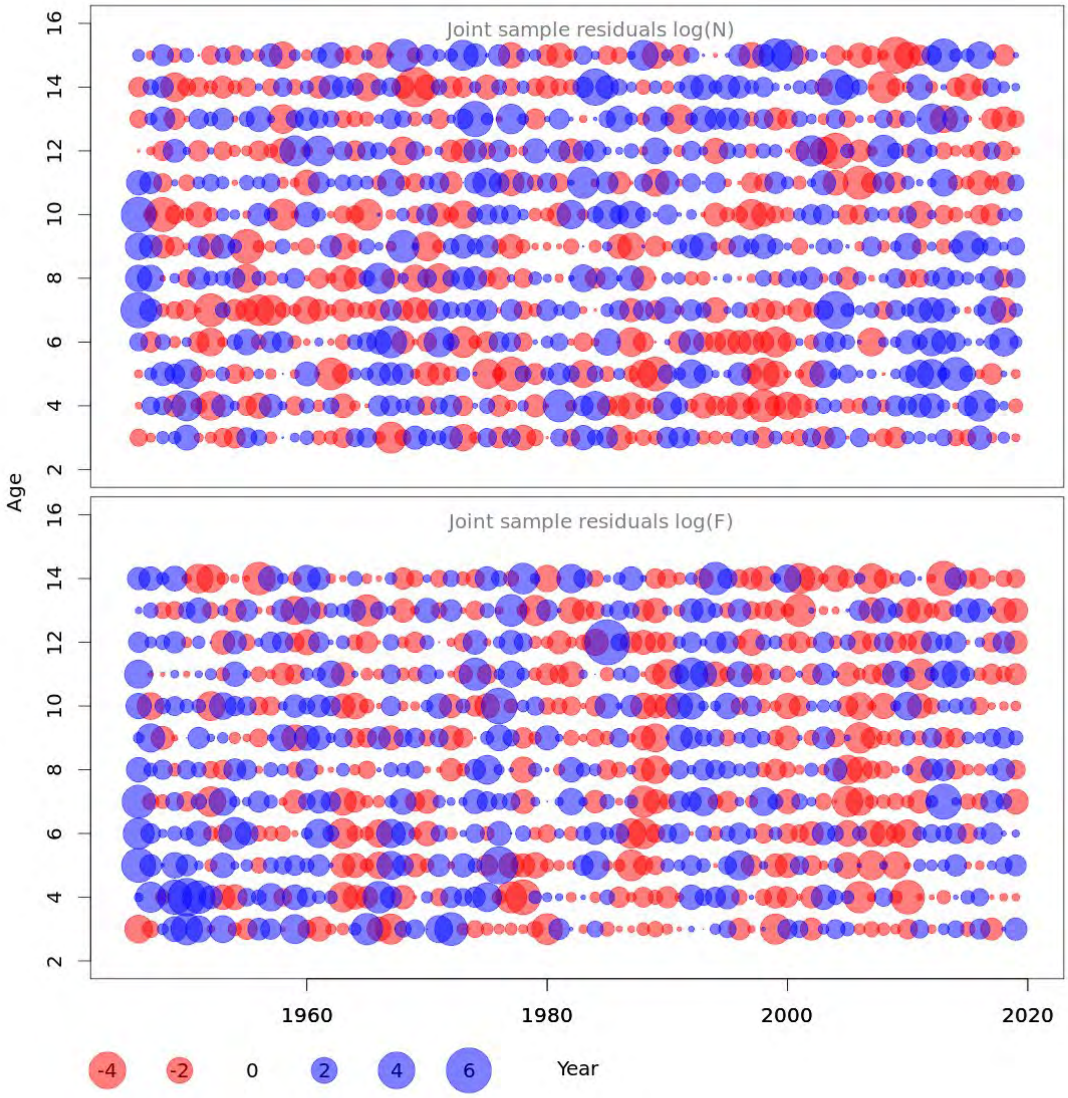
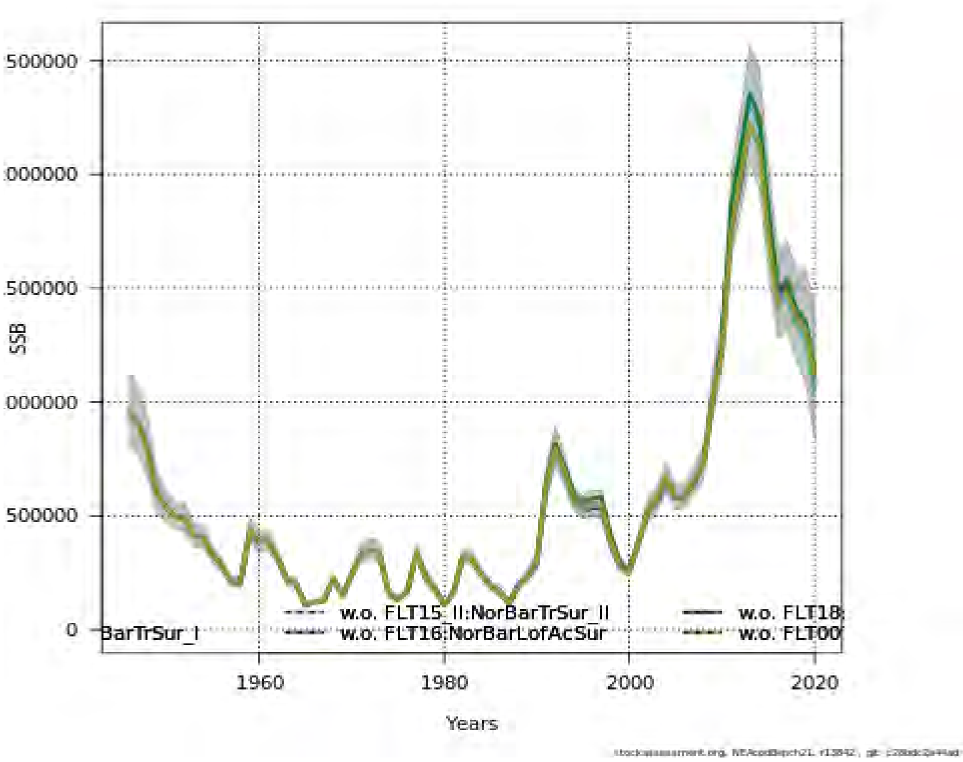


Figure 2.3b. Process errors final model.



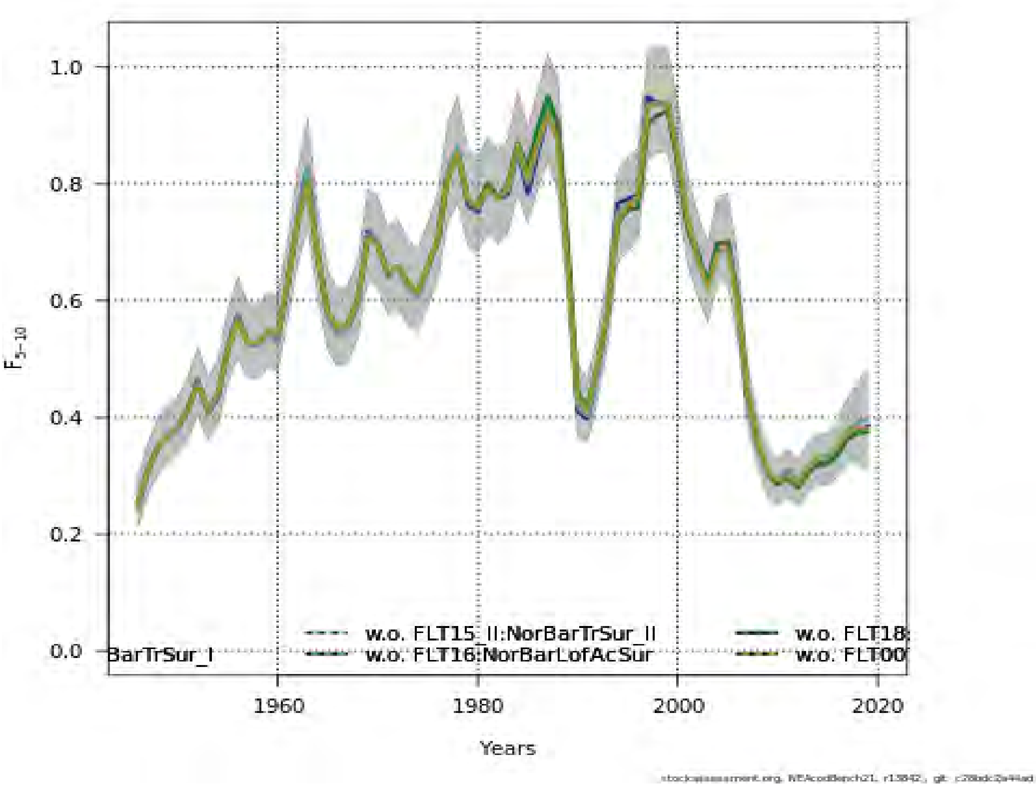


Figure 2.4a–b. Leave one out results, Top: SSB, bottom: F.

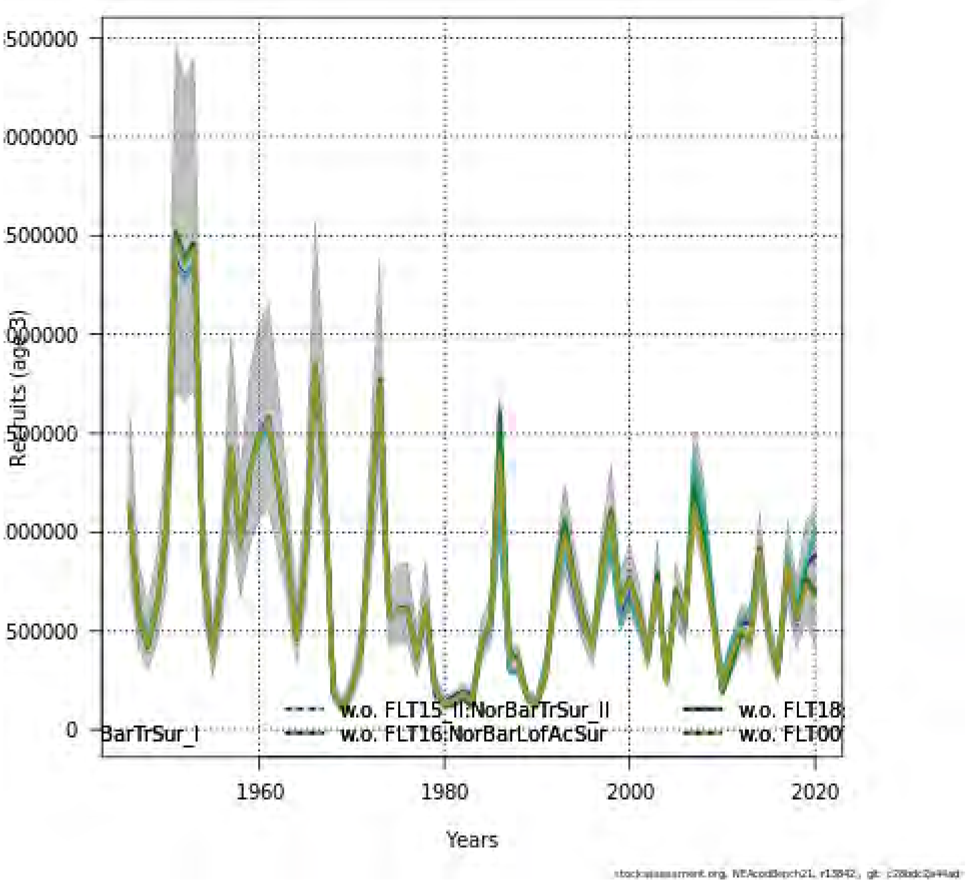


Figure 2.4c. Leave one out results, recruitment.

The results of the final model are shown in Figure 2.5. The results are compared with last years' assessment in Figure 2.6. As for number-at-age in 2020, the final assessment model gave a higher estimate for ages 4 and 5, and lower for all older ages when compared to the 2020 AFWG assessment.

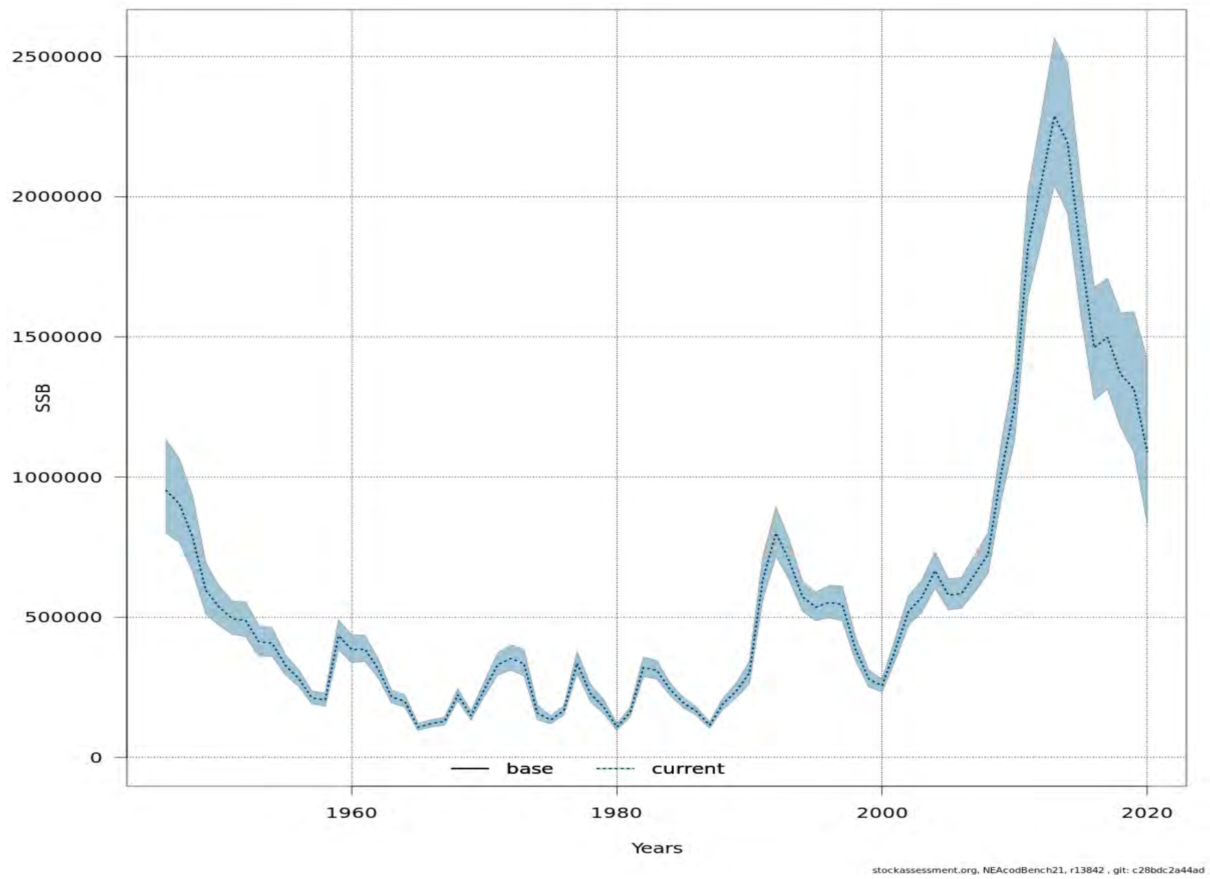


Figure 2.5a. Final model result SSB.

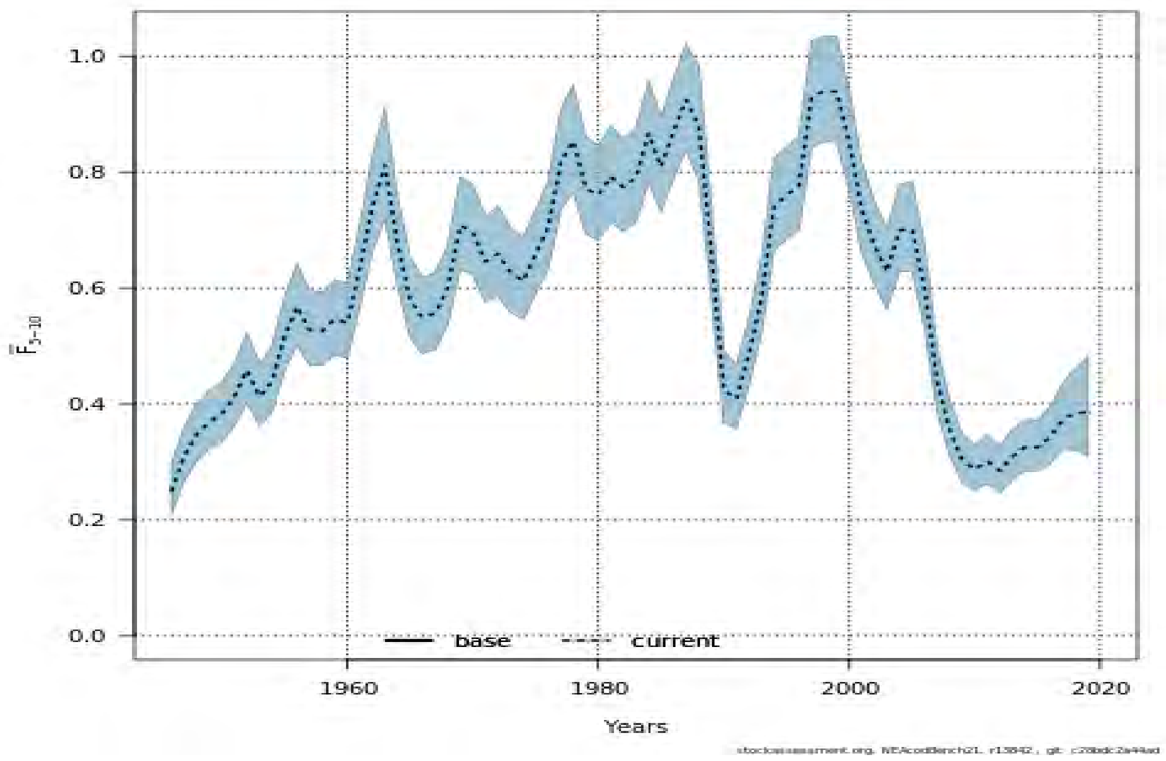


Figure 2.5b. Final model results F_{bar}.

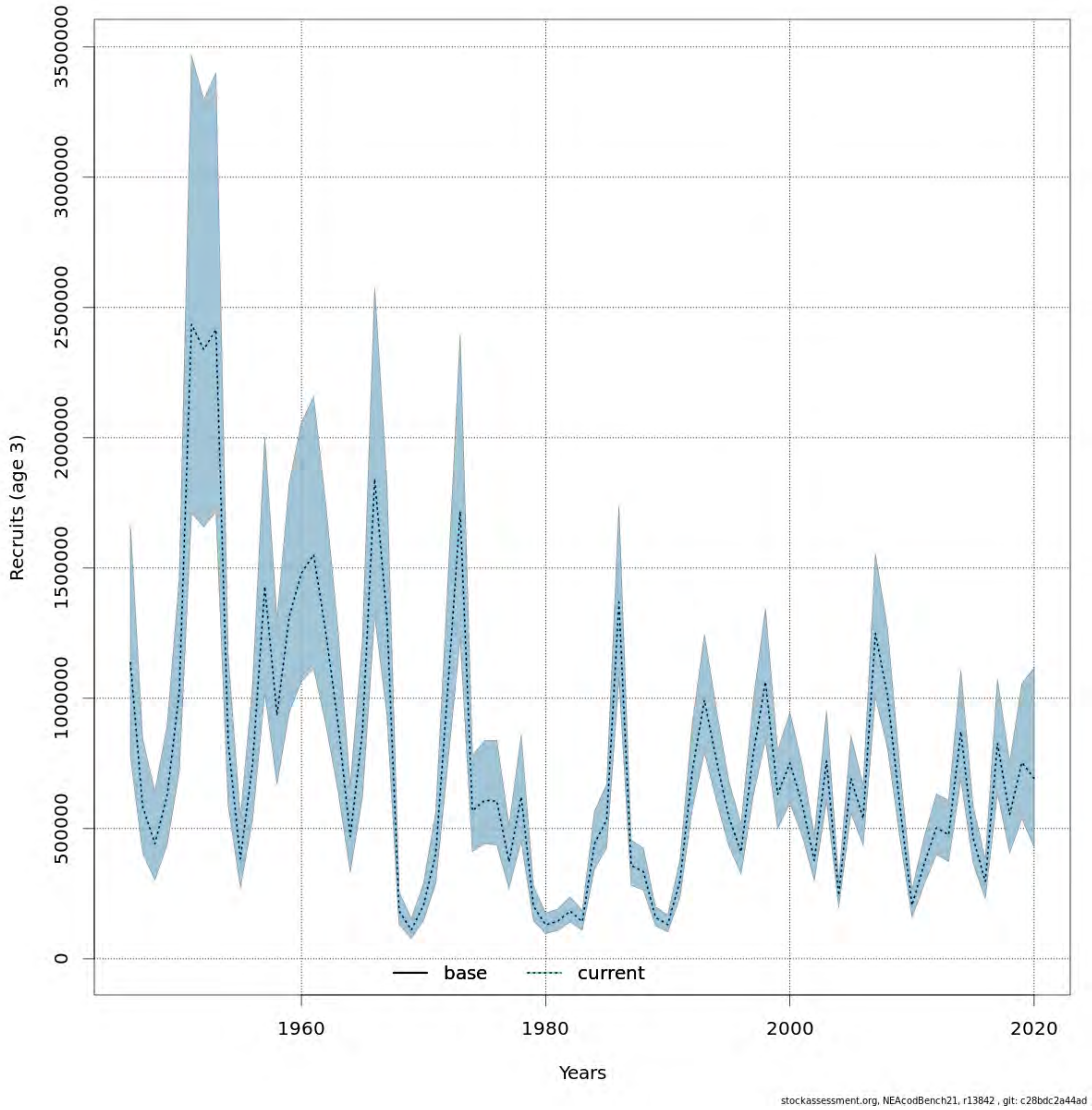


Figure 2.5c. Final model results recruitment.

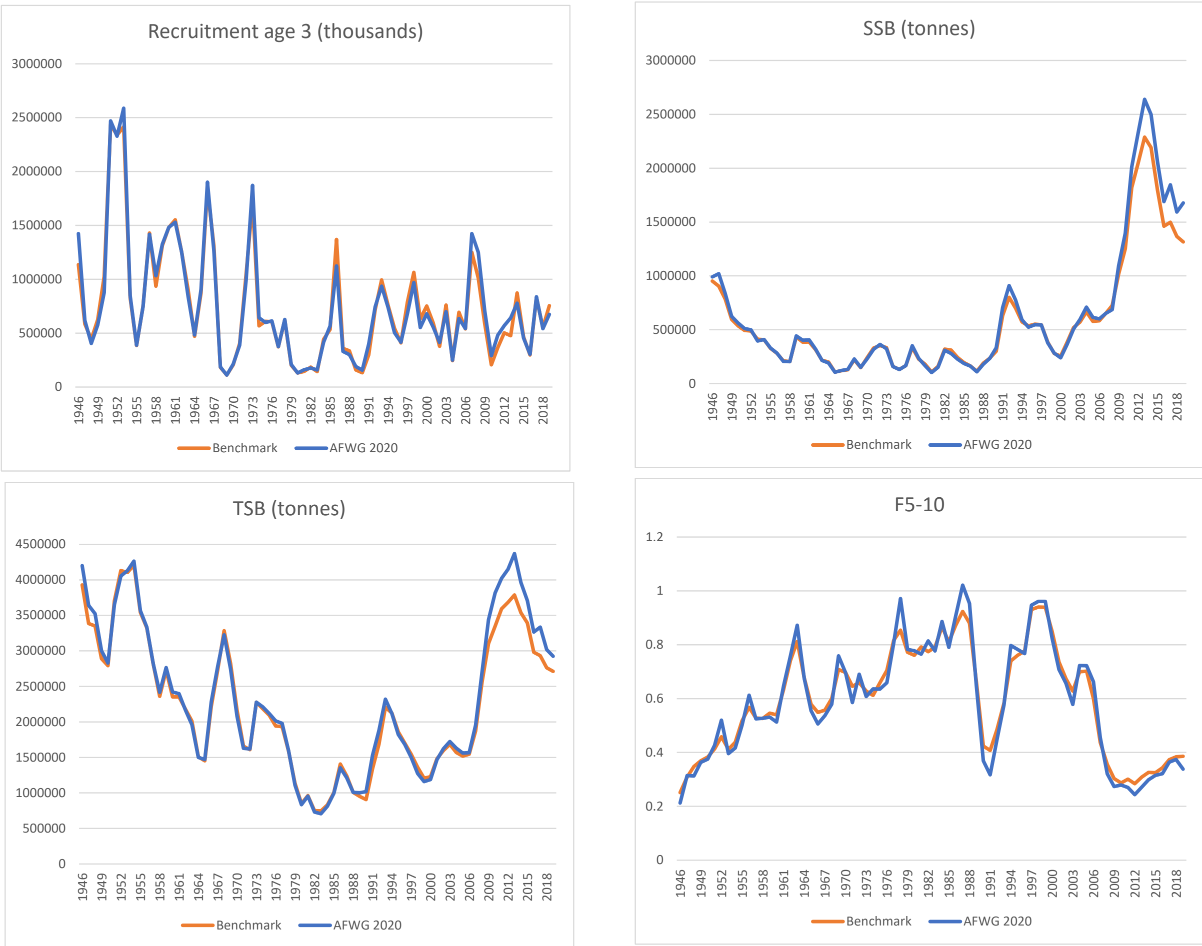


Figure 2.6. R, SSB, TSB and F in the assessment from this benchmark compared to the AFWG 2020 assessment.

2.2.2 Short-term prediction

Some alternative methods for short-term predictions were explored during the benchmark (e. g. WDs 25, 27, 28, 30) but few improvements to the current method were found.

For catch weight-at-age for ages 3–11, it was decided to use five-year average of increments instead of ten-year average (supported by analysis in WD28).

In addition, the method for predicting catch and stock weight-at-age for ages 12–15+ were changed to the same approach used for calculating these weights in the historic time-series (Section 2.3.1).

2.2.3 Reference points

The values adopted by ACFM in 2003 are B_{lim} = 220 000 t, B_{pa} =460 000 t, F_{lim}=0.74, F_{pa}=0.40 (ICES CM 2003/ACFM:11). An updated stock–recruitment plot is given in Figure 2.7.

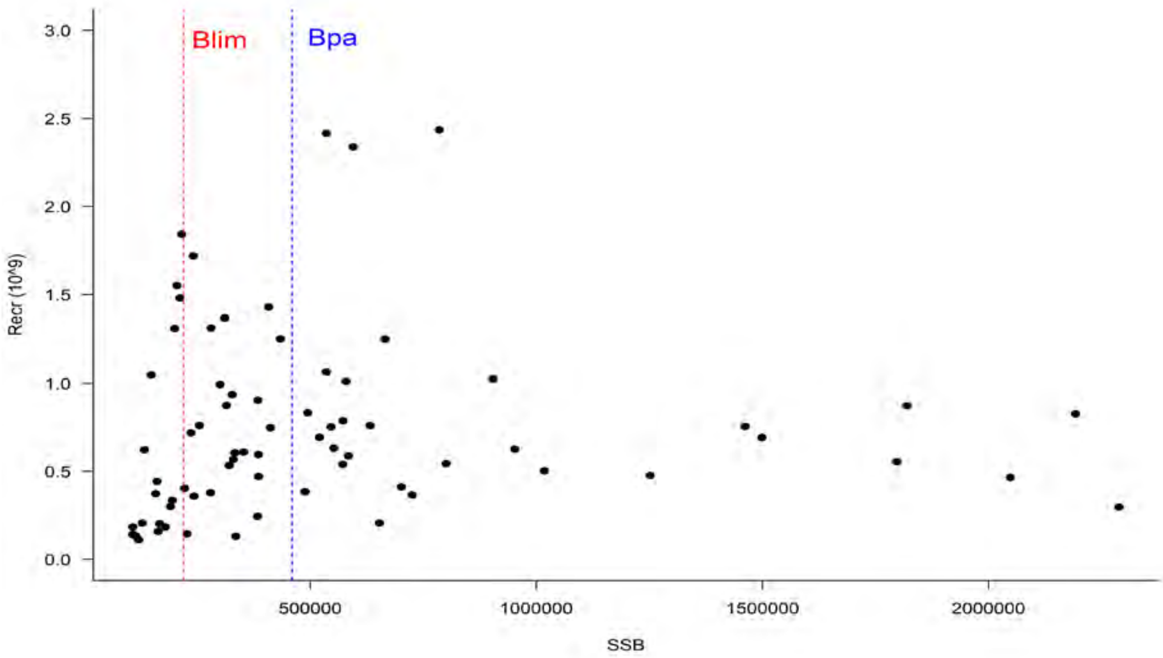


Figure 2.7. SSB-recruitment plot, year classes 1946–2017.

It was noted that the usual Eqsim approach is not appropriate for calculating F reference points because:

- The stock is seen to have strong density-dependence;
- The assessment model has density-dependence through cannibalism;
- The population model used in HCR evaluation of F_{MSY} has additional density-dependence (growth, maturation);
- Density-dependence is currently not included in EqSim, and it can therefore not do the Fp_{05} calculation.

But we do have an evaluated HCR which does utilize the reference points.

Since the EqSim approach cannot be used, it was decided to keep the current reference points (checking that they are precautionary) until the next HCR evaluation, which should be coming soon, probably in 2022, with managers and industry being asked if they have suggestions for alternative HCRs.

It was also concluded that it is reasonable to keep the B_{lim} value. Since this value was determined, SSB has been well above B_{lim}, so there are no new observations of recruitment when SSB is close to B_{lim}. The conclusion was to keep the B_{lim} value as it still seems reasonable.

A check that the existing HCR is still precautionary was carried out (WD 31).

The approach taken was the same as in the HCR evaluation made in 2016 WKNEAMP-2 ICES, 2016). Revised data and five new years of data were added, and the submodels for density-dependent processes (growth, maturation, cannibalism, recruitment) was updated. Overall R^2 values for these submodels improved slightly.

The model was run with age 13+ instead of 15+, because that is how the model is set up. Overall, the existing model still looks valid. There were slight changes in yield suggesting that F_{MSY} could be a little higher. Using a limited number of iterations (1000 iterations instead of 10 000) gave values of predicted catches and stock levels very close to those obtained in 2016. Precautionarity is still solid (less than 1% risk, less than 5% probability of going below B_{lim} even once in 80 years.

Conclusion: keep reference points as they are until the next HCR evaluation.

Considering F_{MSY} (currently quoted as 0.40), the conclusion of the benchmark is to define F_{MSY} as 0.40–0.60 depending on stock size. F = 0.40 and 0.6 corresponds to the lower and upper plateau in the HCR based on the action of density-dependent processes for this stock, and we note that the yield vs F curve is very flat in that range.

2.3 Investigations undertaken (summary)

2.3.1 Dataset

Survey indices

Joint Barents Sea winter survey (bottom trawl and acoustic): Slight revision in method for calculating survey indices (WD1). Indices for extension of survey area from 2014 onwards considered for inclusion in series (they were included, for the bottom trawl survey it was decided to split the survey in 2014 (see Section 2.3.2).

All surveys: Replaced indices for age 12 with indices for age 12+ in the tuning series (this option in SAM was first made available at WKDEM in 2020 (ICES, 2020b).

Lofoten survey: data revised for 2010–2020.

Age 3 added for Joint Barents Sea winter survey (trawl+acoustic).

Weight-at-age in stock and maturity-at-age

Weight-at-age in stock (age 1-11): Revised data from winter and Lofoten survey used for update, and ecosystem survey data are now also included in calculations (WD 12). See stock annex for details.

Maturity-at-age: revised based on revised data from winter survey. Method unchanged.

Weight-at-age in stock ages 12+: new method using cohort-based von Bertalanffy approach used to replace previous fixed values for years 1983-present (WD 12).

Catch data

Weight-at-age in catch data for ages 12+ for years 1983-present changed, similarly as for weight-at-age in stock (WD 12) for these age groups.

A proposal for revision of the historical Norwegian catch data (catch-at-age/weight-at-age in catch/catch in tonnes) from 1994–2019, similar to that made for coastal cod was presented to the meeting (WD 6 and WD 7), The existing methodology has been in use since 2014, and thus the major impact of the proposed revision would be in the period 1994–2013 with more minor revisions in the period 2014–2019. WKBarFar decided not to accept this proposal for use in the assessment as data for many years and age groups (especially ages 12+ in years prior to 2013) were changed considerably and the reason for this was not sufficiently explained. During the meeting, it was noted that the existing catch-at-age data also appear inconsistent for these age groups, and *ad hoc* measures were taken to handle that, see Section 2.3.2. The meeting therefore recommends that further work be conducted on revising the catch data, with a review as part of a subsequent AFWG meeting to evaluate if the revised data should be adopted in the assessment.

Cannibalism data

The data on cod cannibalism used in the assessment were not changed and were not scrutinized.

2.3.2 SAM Model settings

At the meeting, we tried out several SAM model configurations. In this subsection, we summarise the steps made at the meeting to arrive at the final model. We used AIC values, model results and retrospective patterns to guide us through the various steps. An overview of the runs available on stockassessment.org are listed in the end of this subsection.

The parameter space was explored by starting with the 2020-assessment configurations. We started with investigating catchability (conf$keyLogFpar and conf$keyQpow), observation variance (conf$keyVarObs and conf$predVarObsLink), observation correlation (conf$keyCorObs) and fishing mortality increment variance (conf$keyVarF).

A proposal for conf$keyCorObs and conf$keyVarF with improved model fit was obtained. However, it was always observed a clear retro in SSB with all configurations investigated. We decided therefore to investigate how the retros are affected by including revised data step by step. After a couple of days, it was decided to not include the revised catch data and that the Barents Sea bottom trawl survey should be divided into two series (1981–2013 and 2014–2020).

Parameters related to the split survey (conf$keyLogFpar, conf$keyQpow, conf$keyVarObs, conf$predVarObsLink and conf$keyCorObs) was decided to be coupled across the two time-series, except for the catchability parameter (conf$keyLogFpar). This results in that nine addition model parameters are included. Then we started searching through suggestions for conf$keyLogFpar, conf$keyQpow, conf$keyVarObs, conf$keyCorObs and conf$keyVarF.

Linking of catchabilities was not changed from the previous settings, while the coupling of correlation parameters was changed (eight fewer parameters and somewhat different couplings than previously). Also, for some age groups, we added separate observation variances by age within surveys and catch (eight more parameters) as well as separate process variance parameters for fishing mortality process (one more parameter, we added a separate parameter for age 3).

Combining all these settings, however, introduced a pattern in the F-bar retro, especially in the recent 2–3 years. Various different ideas were investigated to solve this issue.

Removing the correlation structure between ages within year for the fishing mortality increments (conf$corFlag=0) approximately removed all visible retro patterns for F_{bar}. However, there was a small retro pattern visible for TSB. At this stage, it was also noted that in the catch matrix, in years 1989–2003 (and one case in 1981) there are several values of 1 for ages groups 13, 14 and 15+, which may be artificial, and also in many cases seem inconsistent with observations for the same cohorts in other years (e.g. catches for the 1982 cohort being 222-82-1 for ages 13–14–15+ respectively). As an interim solution, it was decided to replace these values with NA (not available) in the dataset. When investigating this after the meeting, some, but not all, of those 1-values were consistent with the data found in the archives of catch-at-age.

It was then tried to combine that proposal with the relation between the observation prediction and associated variances (conf$keyVarObs and conf$predVarObsLink), which was implemented for NEA haddock at WKDEM in 2020 (ICES, 2020b). By including the relation between observation predictions and observation variances for all surveys except the Russian survey, a clear improvement of model fit (AIC changed with -98 and only one more parameter was added in total) and the small retro pattern for TSB was removed. It was discussed whether this link should or should not be included in the final model. During the meeting with the reviewers, it was observed that the differences obtained by including the prediction–variance relation was very small for estimated SSB, F_{bar}, recruitment and TSB, and it only had a minor effect on the catch predictions (which often are predicted closer to the observed value when including the prediction–variance relation). One of the reviewers highlighted that the prediction–variance relation was a new option that is currently not widely used, and therefore less validated compared to using constant variances across time. However, he was positive to include it, if we proposed it. It was also highlighted that including such a new structure in SAM should be done at an earlier stage in the meeting to be better validated. We all agreed that the improvement of including the prediction–variance relation was relatively small, and since the prediction–variance relation was proposed relatively late in the meeting and not as thoroughly validated as the option to assume constant variance across time, we decided not to include the prediction–variance relation.

The final SAM model configuration is given in Section 2.7.

During the investigations, the runs were made without the full loop updating the natural mortality due to cannibalism in the retro-runs as this is time-consuming. The final model was, however, run including this loop in the retro-runs and the difference in results was negligible.

The final model was further evaluated by performing a jittered starting points analysis and a simulation validation. Both analyses indicated a robust model.

Below is included a list with key runs on stockassessment.org. Note that number of parameters and AIC change provided are calculated with respect to the previous configuration in the list (if not stated otherwise). When data have changed, the AIC comparison is not included since it is not meaningful to include it. Remember that a reduction in AIC indicates an improved fit. It is indicated if the configuration proposal is included in final model.

1. Configurations as in the 2020-assessment but with the winter survey bottom trawl index split into two periods, different catchability-constant for the split survey, and with parameters for newly included age 3 in two of the surveys. Final dataset is used, except for that suspicious 1-observations in catch are not replaced with NA. Link: NEAcod-bench_pg_age3_old_catch_splitBtr
2. As 1, but with new proposal for observation correlation structures (used in final model, eight fewer parameters, AIC change: -57). Link: splitBtrcodNewcor1
3. As 2, but with separate common variance parameter for catch of two oldest ages (not used in final assessment because of better proposal later, 1 more parameter, AIC change: -192). Link: neacod_day3_base
4. As 3, but with new proposed observation variances (used in final model, seven more parameters and AIC change: -292). Link: neacod_day3_base_obsVar1
5. As 3, but with new proposed F-process variances (used in final model, include one more parameter, AIC change : -40). Link: NEAcod-day3_VarF1
6. Combine 2,4, and 5 (One more parameter included and AIC change: -545 compared to model 1). Link: neacod_day3_base_prop2
7. As 6, but including density-dependent catchability for ages 3 to 11 in the four surveys, by including four extra parameters (Qpow), one by survey fleet. Link: neacod_day3_base_prop2_Qpower
8. As 6, but with independent F-increments within years (used in final model, one fewer parameter and AIC change: +423, included because of less patterns in F-retro). Link: neacod_day3_base_prop2_indepRW
9. As 8, but replace suspicious 1's in catch matrix with NA (meaning not observed). This is the final model with final dataset. (Note that data differ, so can't compare AIC) Link: NEAcodBench21
10. As 9, but with proposed prediction–variance link (not in final model, one more parameter, AIC change: -98). Link: NEAcodBench21_predVarLink

2.3.3 TISVPA model

For comparison the TISVPA model is run annually by AFWG as an auxiliary model. Settings of the TISVPA model were similar to those used at AFWG 2020, except the model was now modified to give possibility to use +group in surveys for ages younger than the oldest age in the assessment. The results are presented in WD-32. Despite the TISVPA model being quite different from SAM, the results are generally similar.

2.4 Research recommendations

When the revision of the historical Norwegian catch data is ready, it should be submitted to ICES for review, ideally by a review attached to the AFWG.

Unify methods for estimating indices from ecosystem survey (currently estimates with both the Biofox and StoX software are provided annually, Biofox estimates are used in the assessment).

Age 3 abundance in assessment year: What is better – use SAM estimate or recruitment model?

Look at how the correlation between F-at-age may have changed over time, and if necessary, see if we can adjust SAM to account for this. Consider implementing changes in correlation of F random walk over time in SAM.

Use of prediction–variance link in SAM (should be published).

2.5 Reviewer's comments

The reviewers support the adoption of the proposed SAM model as the basis of ICES advice. For full reviewer comments see Section 6.

2.6 References

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ICES. 2020b. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548

2.7 SAM configurations

The order of fleets in sets of parameters:

Catches

Tuning fleet 1 (first part)

Tuning fleet 1 (second part)

Tuning fleet 2

Tuning fleet 3

Tuning fleet 4

Configuration file:

```
$minAge
# The minimium age class in the assessment
 3
$maxAge
# The maximum age class in the assessment
 15
$maxAgePlusGroup
# Is last age group considered a plus group (1 yes, or 0 no).
 1 1 1 1 1 1
$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
  0  1  2  3  4  5  6  7  8  9 10 11 11
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
$corFlag
# Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, or 2 AR(1)
 0
$keyLogFpar
# Coupling of the survey catchability parameters (normally first row is not used, as that is covered by fishing mortality).
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 0  1  2  3  4  5  6  7  8  8 -1 -1 -1
 9 10 11 12 13 14 15 16 17 17 -1 -1 -1
 18 19 20 21 22 23 24 25 26 26 -1 -1 -1
 27 28 29 30 31 32 33 34 35 35 -1 -1 -1
 36 37 38 39 40 41 42 43 44 44 -1 -1 -1
```

```
$keyQpow
# Density-dependent catchability power parameters (if any).
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
$keyVarF
# Coupling of process variance parameters for log(F)-process (normally only first row is used)
  0  1  1  1  1  1  1  1  1  1  1  1  1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
$keyVarLogN
# Coupling of process variance parameters for log(N)-process
 0 1 1 1 1 1 1 1 1 1 1 1 1
$keyVarObs
# Coupling of the variance parameters for the observations.
  0  1  2  2  2  2  2  2  3  3  4  4  4
  5  6  6  6  6  7  7  7  7  7 -1 -1 -1
  5  6  6  6  6  7  7  7  7  7 -1 -1 -1
  8  8  8  8  8  8  9  9  9  9 -1 -1 -1
 10 10 10 10 10 10 11 11 11 11 -1 -1 -1
 12 12 12 12 12 12 12 12 12 12 -1 -1 -1
$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"
 "ID" "AR" "AR" "AR" "AR" "AR"
$keyCorObs
# Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
#3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12 12-13 13-14 14-15
NA NA NA NA NA NA NA NA NA NA NA NA
```

0 0 0 0 1 1 2 2 3 -1 -1 -1

0 0 0 0 1 1 2 2 3 -1 -1 -1

4 4 4 5 6 6 6 7 8 -1 -1 -1

9 9 9 9 10 10 10 11 -1 -1 -1

12 12 12 13 13 13 14 14 15 -1 -1 -1

$stockRecruitmentModelCode

Stock–recruitment code (0 for plain random walk, 1 for Ricker, and 2 for Beverton–Holt).

0

$noScaledYears

Number of years where catch scaling is applied.

0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange

lowest and higest age included in Fbar

5 10

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, and 2 FSB index).

-1 -1 -1 -1 -1 -1

$obsLikelihoodFlag

Option for observational likelihood | Possible values are: "LN" "ALN"

"LN" "LN" "LN" "LN" "LN" "LN"

$fixVarToWeight

If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).

0

3 Norwegian coastal cod (*Gadus morhua*) north of 67°N

3.1 Why a benchmark?

The 2021 benchmark was proposed in order to address the failure of the current management plan to reduce fishing mortality on coastal cod. The rebuilding plan has been in operation for ten years, which implies that the fishing mortality in 2019 should have been at least 60% lower than the 2009 value. The 2019 data indicated a fishing mortality 17% below the F in 2009 (based on the previous assessment method; ICES, 2020). The regulations have therefore not been sufficient for constraining the coastal cod catches.

The majority (80%) of coastal cod catches are taken north of 67°N (Table 3.1). This is also where the coastal survey has best coverage and genetic studies suggest a more homogenous subpopulation (Dahle *et al.*, 2018). Recent updates of the catch series, a revision of the acoustic survey index and a new swept-area index have improved the data basis for assessment in the northern area. As part of the work with developing a new management plan for this stock, it was therefore proposed to split the stock in two by 67 degrees latitude, north of which the data were considered of high enough quality to support an age-based analytical assessment (Aglen *et al.*, 2020).

3.2 Summary of final model

The final assessment model is a State–Space Assessment Model (SAM, Nielsen and Berg, 2014) based on revised catch and survey data. The model has been approved by the benchmark as a basis for category 1 assessment of Norwegian coastal cod north of 67°N.

The catch data include estimates of recreational catches as a constant annual cap in tonnes split by age according to the age structure in commercial landings from the same year. Three tuning series are used: two acoustic (1995–2002, 2003–) and one swept-area (2003–), all from the Norwegian annual coastal survey in autumn (NOcoast-Aco-4Q). The survey takes place in October–November while spawning is in March–June, causing some challenges for estimation of biological parameters for the assessment model. To address this issue, the proportion of F and M before spawning was set to 0.8 (i.e. 80% of the annual F and M are applied before calculating SSB). This means that we artificially shift the spawning to late October to match data on stock weights and maturity ogives collected at this time of year. It is important that reference points and the future management plan/harvest control rule consistently relate to SSB at this time of year.

The start year of the assessment is 1994, and the model was run up until 2019 at the benchmark. The revised catch data are available for the entire period, while the survey indices start in 1995/2003. Revision of catch data back to 1984 was not ready in time for the benchmark, and will be presented for review at a later short review in connection with the Arctic Fisheries Working Group. If these data are approved, the model may be extended further back in time. The age range in the new assessment model is 2–10+ and F_{bar} is the average F for ages 4–7.

The model output shows one peak of SSB around 1995 and another in 2014–2015, but with lower recruitment for similar SSB in the latter period (Figure 3.1). F_{bar} was highest in the first years and reached its lowest value in 2014, after which it has increased to a level similar to the early 2000s. A reduction in F is indicated for the last two years.

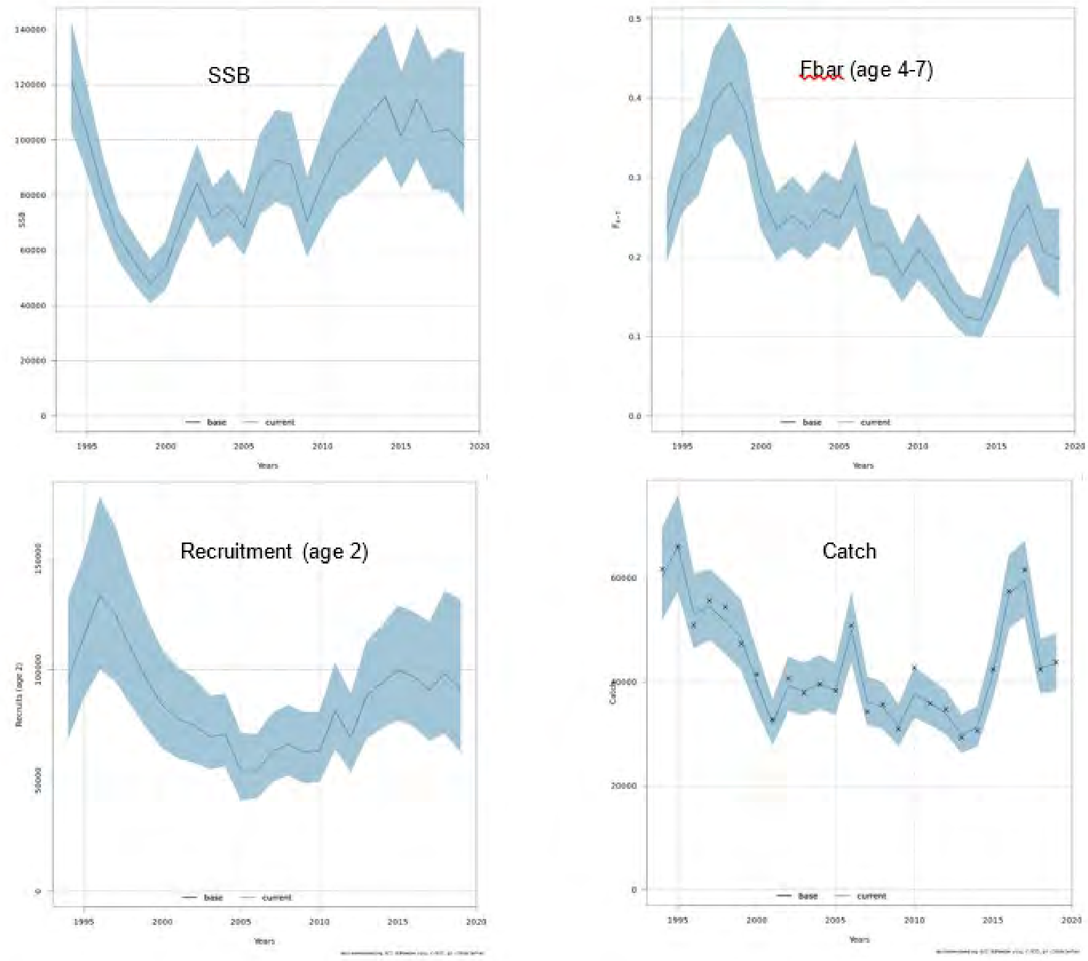

Figure 3.1. Final model results. SSB and catches in tonnes, recruitment in thousands.

The one-step-ahead and process residuals have some minor remaining patterns but have been much improved by changes to the SAM configuration (Figure 3.2, WD-26, and below).

Overall, the retrospective pattern of the model is acceptable (Figure. 3.3). The retro on SSB shows some underestimation in the years up to 2012 and some overestimation in the following years, while in later years, estimates are close to the final run (Figure 3.3). The largest uncertainty is observed for recruitment.

Leaving out the acoustic index part 1 has a small effect, though it appears to pull the estimate of SSB slightly downwards even in the last years (Figure 3.4). Leaving out the acoustic index part 2 has a similar effect as leaving out the swept-area index; an increase in SSB particularly in later years with high biomass.

The model was further evaluated by performing a jittered starting points analysis and a simulation validation. Both analyses indicated a robust model (WD-26).

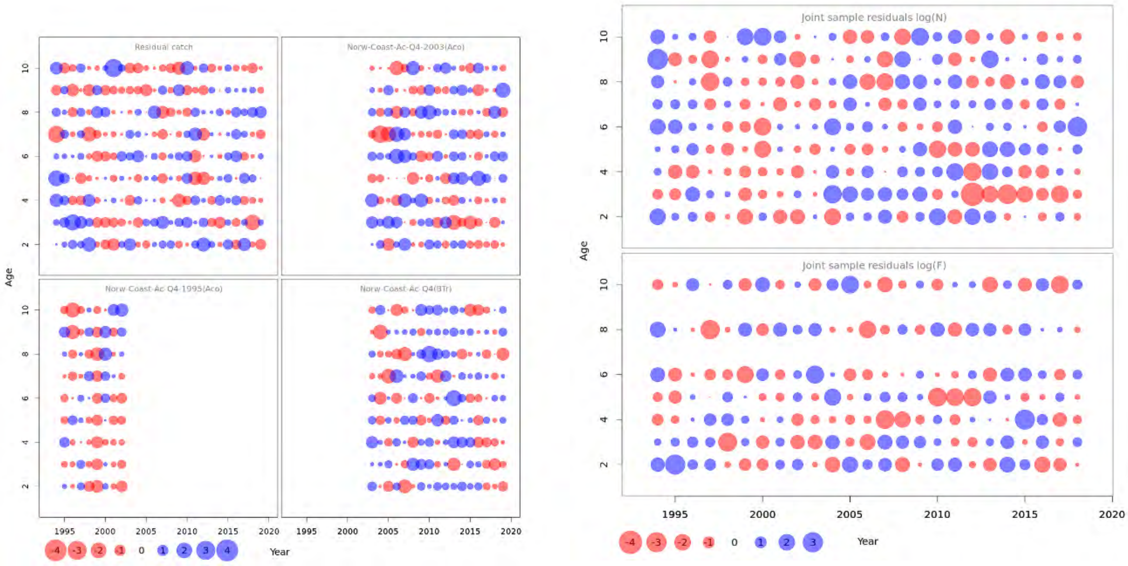

Figure 3.2. One-step-ahead residuals (left) and process residuals (right) from the final model.

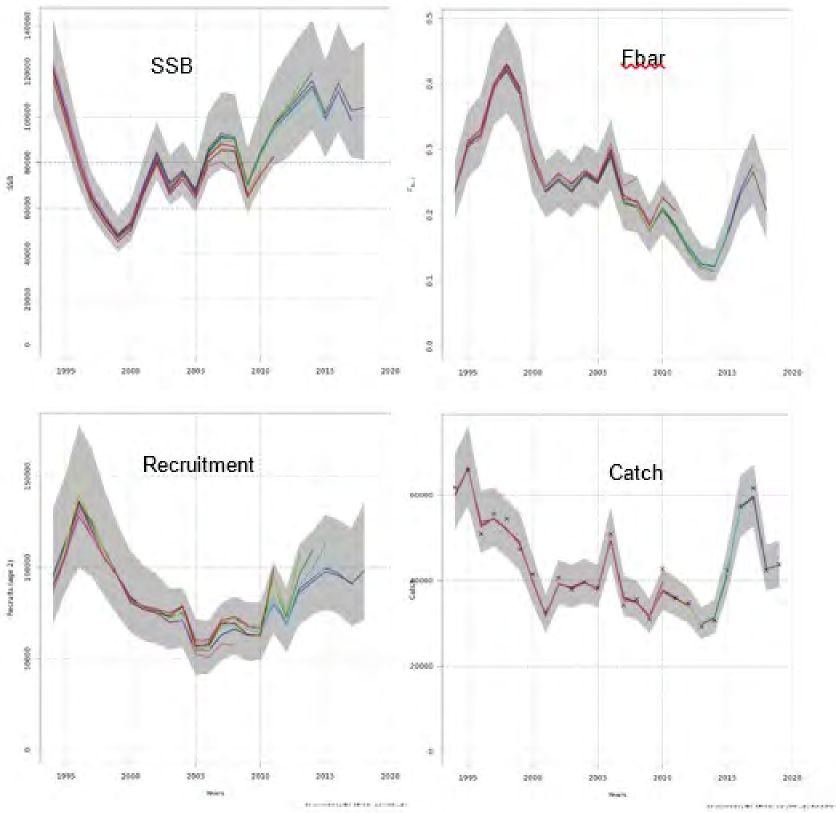

Figure 3.3. Ten-year retrospective peel from the final model. Mohn's rho (five-year retrospective bias) on SSB: 0.01, F_{bar}: -0.009, recruitment: 0.22.

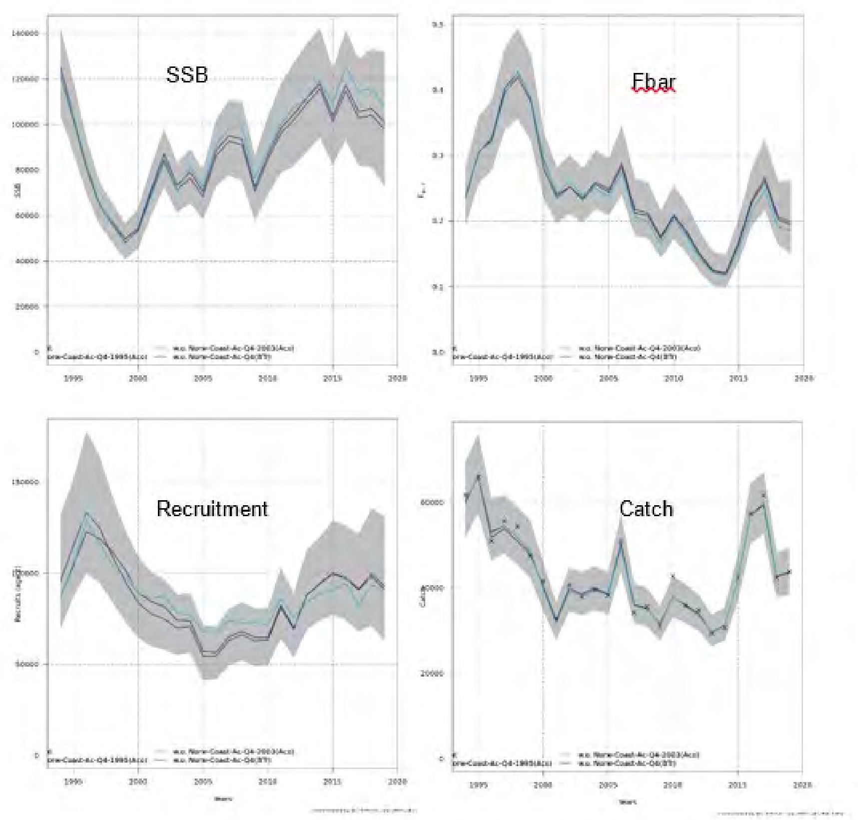

Figure 3.4. Leave-fleet-out run for the final model. Dark blue = leaving out acoustic index part 1, light blue = leaving out acoustic index part 2, green = leaving out swept-area index.

3.3 Input data

3.3.1 Catch data (age 2–10+, WD-26 Table A3)

The revised catch data (1994–2019, 2020 will be available in March 2021) include commercial catches and an estimate of recreational catches (Table 3.1). The revision included an update to the most recent catch statistics and adjusting conversion factors between gutted and round weight to seasonal values for some parts of the fleet. More details on the catch data revision can be found in WD-7.

The estimate of recreational catch is a constant catch in tonnes added each year and split by age, based on the age structure in the commercial catches (same method used previously, but split on the south/north areas). There is ongoing work to obtain annual estimates of recreational catch for later years (WD-13).

We assume that all fish caught commercially are landed, i.e. no discards, as discarding is banned in Norwegian waters. Some minor discards may occur, mainly in gill net fisheries (less than 1% in weight of total cod catch), where scavengers occasionally reduce the catch quality (Berg, 2019; Berg and Nedreaas, 2021). The recreational catches include estimates of discards (mainly from catch-and-release) for which the assumption is 20% mortality (WD-13).

Table 3.1. Left - estimated commercial catches of Coastal cod north of 67˚N and between 62-67˚N, and Northeast Arctic cod between 62-67˚N. Right – estimated recreational catches of cod north of 67˚N and between 62-67˚N, all assumed to be coastal cod. Note that an unlikely low share of NCC vs NEAC in the 2001 commercial landings compared to years before/after was replaced by an average of the 2000 and 2002 NCC values.

Commercial catch (in tonnes):				Recreational catch (in tonnes):			
Year	Coastal cod	Coastal cod	NEA cod	Year	Coastal cod	Coastal cod	Total
	N of 67˚N	S of 67˚N	S of 67˚N		N of 67˚N	S of 67˚N	recreational
1994	52 579	6 381	23 430	**1994**	9 144	5 556	14 700
1995	56 907	8 936	16 981	**1995**	9 144	5 556	14 700
1996	41 820	6 207	13 250	**1996**	9 020	5 480	14 500
1997	46 605	4 746	12 695	**1997**	9 020	5 480	14 500
1998	45 462	6 200	9 389	**1998**	9 082	5 518	14 600
1999	38 743	5 522	7 101	**1999**	8 646	5 254	13 900
2000	33 081	5 838	4 329	**2000**	8 460	5 140	13 600
2001	24 470	*5 250*	*3 499*	**2001**	8 335	*5 065*	13 400
2002	32 188	6 937	4 266	**2002**	8 460	5 140	13 600
2003	29 253	8 905	3 943	**2003**	8 646	5 254	13 900
2004	31 198	6 866	3 941	**2004**	8 335	5 065	13 400
2005	30 097	8 005	1 462	**2005**	8 211	4 989	13 200
2006	36 884	8 612	1 175	**2006**	8 087	4 913	13 000
2007	26 200	7 695	2 250	**2007**	8 087	4 913	13 000
2008	27 711	9 889	1 376	**2008**	7 962	4 838	12 800
2009	22 988	7 145	2 474	**2009**	7 900	4 800	12 700
2010	34 804	7 634	2 685	**2010**	7 900	4 800	12 700
2011	27 982	7 128	7 474	**2011**	7 900	4 800	12 700
2012	26 778	8 187	4 942	**2012**	7 900	4 800	12 700
2013	21 376	5 131	8 395	**2013**	7 900	4 800	12 700
2014	22 750	6 244	6 682	**2014**	7 900	4 800	12 700
2015	34 483	5 004	5 424	**2015**	7 900	4 800	12 700
2016	49 503	5 962	2 006	**2016**	7 900	4 800	12 700
2017	54 273	4 159	1 242	**2017**	7 900	4 800	12 700
2018	34 532	4 436	1 822	**2018**	7 900	4 800	12 700
2019	35 861	2 965	1 677	**2019**	7 900	4 800	12 700

3.3.2 Survey data (age 2–10+, WD-26 Tables A5-A7)

Coastal cod is surveyed once a year in the Norwegian annual coastal survey in autumn (NO-coast-Aco-4Q). The survey has run since 1995 in October-November each year, first as an acoustic survey only and since 2003 with fixed bottom trawl stations in addition to continuous acoustic registrations. An acoustic index (1995–) from this survey has been used in previous assessments of the entire coastal cod complex but was revised for the benchmark. The revision included collating older datasets and using new software for index calculation. This led to downwards revision of the index in the early part of the time-series. The index was also split by the southern/northern areas under consideration for separate assessments and a new swept-area index (2003–) was calculated. Calculation of the new indices is detailed in WD-14.

The two survey indices are not completely independent as trawl catches are a source of information in the allocation of acoustic backscatter to species and length distributions from trawls are used to split the acoustic backscatter by age. However, there are many areas along the coast that are only accessible with acoustic gear due to irregular topography. Further, acoustic registrations are made throughout the water column, while the trawl samples near-bottom distributions. In cases where pelagic acoustic registrations are allocated to cod, pelagic trawl hauls targeting the registrations are also used to split the acoustic backscatter on coastal cod and NEA cod, and the coastal cod by age. The indices therefore contain some independent information as well. At the WKBarFar data workshop, it was recommended to explore including one series as a total biomass index and the other as numbers-at-age, compared to having both indices disaggregated. After investigations showing low consistency between the two indices and worse model fit and retrospective pattern when using a biomass index, it was decided to keep the split by age in both indices. A decision was also made to split the acoustic index in two periods (1995–2002, 2003–) after a change in catchability was discovered. This change coincided with the introduction of fixed bottom trawl stations in the survey. The investigations are detailed in WD-26.

3.3.3 Biological parameters (WD-26, Tables A4, A8–A10)

Stock weight-at-age 2–7 was taken from the coastal survey (individual samples included in the acoustic index). Weights for ages 8–10+ was set equal to weight-at-age in the catch due to few samples in survey data that gave unreasonably large variation between years. Weight-at-age in the stock in 1994, when we have catch data but no survey data, was for ages 2–7 set to the average weights-at-age in the survey in 1995–1997, and equal to the weight in catch for ages 8–10+. Investigations into possible bias caused by using catch weights, which mainly come from the first half of the year, as stock weights revealed that the weight in catch (average across the year weighted by catch numbers) is not as dissimilar from the weight in quarter 4 as expected (WD-26). This is because catch weights-at-age tend to decrease from Q1 to Q4, likely due to weight loss after spawning in combination with seasonal changes in fishing selectivity.

The maturity ogive was also calculated from coastal survey data. Investigations into these data revealed that many individuals had been classified as spent (stage 4), while fewer were classified as maturing (stage 2) and almost none as spawning (stage 3). Given the timing of the survey in relation to spawning, this was not unexpected, but presented a challenge for obtaining a good estimate of the proportion mature at age. It was decided to include stage 4 as mature in the calculations, as this gave a maturity ogive similar to that estimated from a smaller fishery-dependent dataset from Q1–Q2 (WD-26).

There are no empirical estimates of natural mortality for this stock. To introduce some biological realism, a size-based estimate was used (Lorenzen, 1996). Two other size-based methods for calculating M was also evaluated (WD-18, WD-26), but it was concluded that the Lorenzen M gave a good trade-off between biological realism and possibly unrealistic mortalities for the oldest fish.

3.4 Investigations undertaken–SAM data and configuration (summary)

First, different options for survey data (age-based index vs biomass index) and natural mortality (three different size-based estimates versus constant 0.2) were evaluated. To find the best option for tuning series, models were run with SAM default configuration and constant 0.2 natural mortality. To find the best option for natural mortality, models were run with SAM default configuration and both tuning indices as numbers-at-age. Different data inputs were compared based on residual and retrospective patterns. This resulted in the split of the acoustic tuning series, the decision to keep all indices disaggregated with respect to age, and the use of a weight-based M (Lorenzen, 1996).

Second, SAM internal configurations were explored in the following order: 1. Coupling of fishing mortality states, 2. Coupling of survey catchabilities, 3. Coupling of observation variances, and 4. Correlation between ages in the observations. Each configuration was evaluated separately, e.g. different options for coupling of Fs were tried while the rest of the configuration was kept at default. To find the optimal configuration, the model was fit as freely as possible, i.e. each age was given its own parameter. The fit was then evaluated to see if certain ages had similar parameter estimates and could be coupled (given the same parameter). New run(s) were made with coupled parameters and the default, free, and coupled configurations were compared by means of AIC, residual and retrospective patterns. The best configurations are summarised below, and step-by-step details and figures are found in WD-26.

1. Fishing mortality (keyFsta)

Fishing mortalities for ages 7–9 were coupled, i.e. restricted to the same parameter estimate, as the free F configuration indicated that these ages had similar fishing mortalities. All other ages were given their own parameter (level of F). This change resulted in lower SSB estimates with smaller confidence intervals in the first years, and a somewhat better fit to catch data compared to the default configuration where Fs for the last two ages are coupled.

2. Catchability (keyFpar)

For the acoustic index part 1, catchability for ages 5 and 6 were similar and given the same parameter. For the acoustic index part 2 and the swept-area index, ages 5–9 were coupled. There was a clear difference in catchability between the acoustic indices part 1 and 2, both in terms of the level and the selection pattern, which was more dome-shaped for acoustic part 1. The new catchability coupling resulted in a general increase in SSB and subsequent adjustment to F_{bar} compared to the default of constant catchability for the last two ages.

3. Observation variances (keyVarObs)

Age 2 (youngest age) in the catch was given its own variance parameter based on larger one-step-ahead residuals for this age in the default run with constant variance across ages. The best fit to survey indices were obtained by keeping the default constant variance. The additional parameter for age 2 in the catch resulted in a small upwards revision of SSB and much better fit to catch data.

4. Correlation structures (keyCorObs)

Introducing a free Autoregressive (AR) correlation structure (separate parameters for each age-pair) in the acoustic index part 2 and the swept-area index indicated several clusters of similar correlations between neighbouring age-pairs. For the acoustic index, correlations between ages 5–6 and 6–7 were similar, while in the swept-area index, ages 3–4, 4-5, 5–6 were similar and another group with similar correlations was indicated for ages 7–8, 8–9 and 9–10+. Implementing this correlation structure removed most of the annual patterns observed in the trawl index one-step-ahead residuals and substantially lowered the AIC of the model. A small pattern in the log(N) process residuals were introduced by including correlation structure in the acoustic index part 2, but not including correlation in this index resulted in poorer retrospective pattern on SSB and F_{bar}. Correlation between ages imply that the model derives less information from the single age groups included in a correlated pair. Introducing correlation structure gave higher estimates of recruitment in the first and last part of the time-series compared to the default (no correlations) and resulted in wider confidence bands on SSB and recruitment. No correlation structure was specified for the acoustic index part 1, as this led to the model not converging.

Applying all the changes to the configuration described above lowered the AIC from 727.4 (for default configuration) to 417.3, with the strongest reduction caused by introducing correlation structure. This is the final model approved by the benchmark meeting. The output is shown under “Summary of final model” above and in tables A1–A2 of WD-26. The final configuration can be found in WD-26 Appendix 3. The model is available on stockassessment.org under the name NorwegianCoastalCod_north67N_incl_rec_catch.

3.5 Short-term forecast

The built-in forecast option in SAM was approved for use in short-term prediction. In the forecast, F was set to *status quo* (same as in the terminal year of the assessment; fscale=c(1,1,1,1)) and process noise was included (i.e. processNoiseF=FALSE). Averages from the last five years were used for stock weight, catch weight, and maturity-at-age, and recruitment was resampled from the last ten years. Under *status quo*, the model predicts a highly uncertain increase in SSB in the coming years (Table 3.2, Figure 3.5).

Table 3.2. Forecast table including the terminal year of assessment (2019). Assuming same F as in terminal year for the prediction years.

Year	fbar: median	fbar: low	fbar: high	rec: median	rec: low	rec: high	ssb: median	ssb: low	ssb: high	catch: median	catch: low	catch: high
2019	**0.201**	0.152	0.256	**91742**	63043	134068	**98582**	74553	130727	**43654**	38768	49353
2020	**0.201**	0.152	0.256	**90956**	63324	99790	**106705**	75594	150043	**44895**	38356	52347
2021	**0.201**	0.152	0.256	**90967**	63324	99790	**111797**	74777	164843	**46700**	37992	57212
2022	**0.201**	0.152	0.256	**90956**	63324	99790	**115483**	75441	174399	**47636**	38515	59424

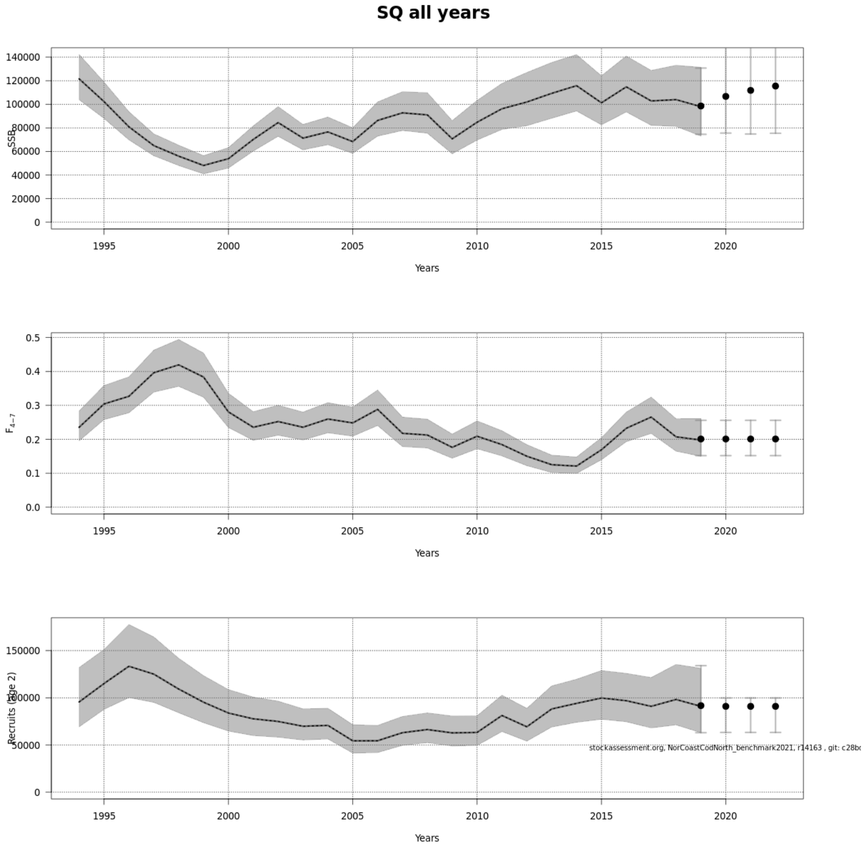

Figure 3.5. Three-year forecast from the final model assuming F *status quo*.

3.6 Reference points

The estimated stock-recruitment relationship generally showed an increase in recruitment (at age 2) with SSB (Figure 3.6). However, the stock appears to have followed a different trajectory in the first 6–7 years of the time-series compared to the years after; the same SSB yielded higher recruitment in the first period. The shape of the stock–recruitment relationship gives little indication that a plateau in recruitment has been reached within the time period considered, and consequently, SSB is likely below B_{lim}. However, with no apparent plateau, estimation of B_{lim} – and consequently, estimation of all other reference points – is highly uncertain.

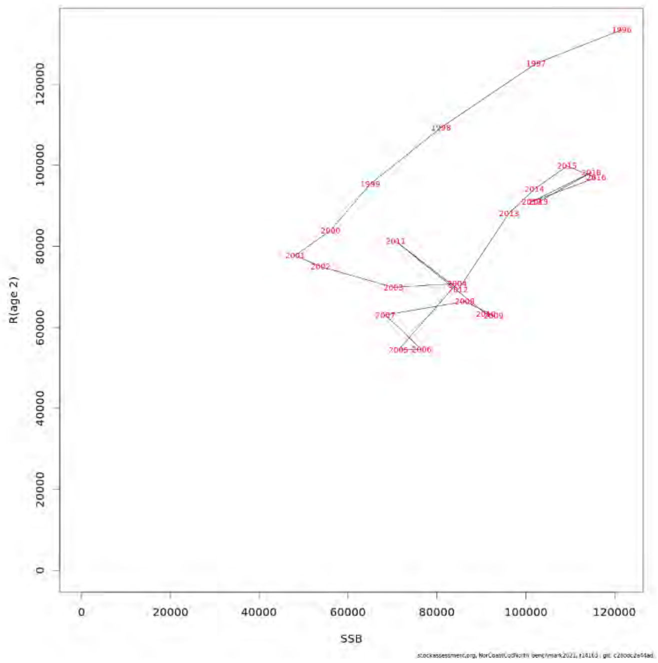

Figure 3.6. Stock–recruitment plot from SAM, where recruitment is modelled as a random walk process. Recruitment at age 2 is plotted against SSB estimated two years previously. The labels in red refer to the year of the recruitment estimate.

The benchmark meeting concluded that the closest ICES stock type to the estimated S–R relationship is Type 3 (ICES, 2017). This is a stock with a wide range of SSB with evidence of impaired recruitment and no clear asymptote in recruitment at high SSB. It was argued that the stock shows evidence of impaired recruitment since recruitment increases with SSB over the range of values observed. Alternative stock types were discussed; Type 5 with no clear S–R relationship and Type 6 with a narrow range of SSB. But as those types are not supposed to show impaired recruitment, they were not considered appropriate.

For a Type 3 stock, B_{lim} may be close to the highest SSB observed, but evaluation of B_{lim} depends on an evaluation of historical fishing mortality and thus rely heavily on expert opinion. Due to the lack of a plateau and years with very low recruitment, a segmented regression was of little help in determining B_{lim}. Using EQSIM, a free segmented regression put B_{lim} at approximately 55 000 t (Figure 3.7 a), rather close to B_{loss}, which seems highly unlikely given the strong increase in recruitment with SSB after this point. Catches of coastal cod were high in the mid-1980s when the fishery along the Norwegian coast was practically unregulated, at least as high as in the first years of the assessment model (see Table 3.2 in ICES, 2020, but NB these catches will be revised). Introduction of strong regulations on the Northeast Arctic cod fishery in the early 1990s followed by regulations on the coastal fishery in the early 2000s seem to be followed by increases in coastal cod SSB and recruitment based on the SAM model results. Based on this reasoning, it was decided to place B_{lim} close to the highest SSB observed.

As the S–R relationship in the early part of the model period followed its own (parallel) trajectory, possibly representing a different state of the stock or the ecosystem, we focused on the S–R relationship in the second part (2003–2017) and set B_{lim} to the highest observed SSB in this period (SSB_{2014} = 115 782 t, shown as 2016 in Figure 3.6). This is approximately 6000 t lower than the highest SSB in the first period (SSB_{1994} = 121 547 t). A segmented regression based on the final B_{lim} is shown in Figure 3.7 b.

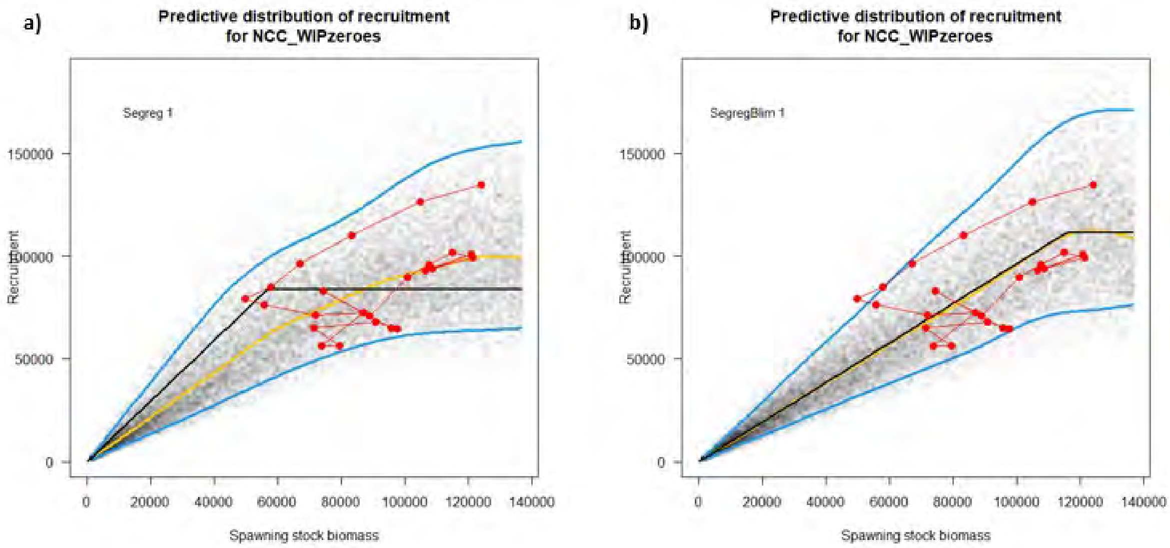

Figure 3.7. Simulations of the coastal cod stock–recruitment relationship from EQSIM. a) free segmented regression, b) constrained segmented regression, with manual specification of B_{lim} to the value approved by the benchmark. The yellow line corresponds to the median of the simulated points and the blue lines surround the 5–95 % quantiles.

An attempt was made to simulate F_{lim}, and MSY reference points from this B_{lim} using EQSIM. In the simulation, averages of the last ten years were used for weight-at-age. For selectivity-at-age, averages of the last five years were used as there was a pronounced increase in selectivity of ages 7–9 in recent years. This is likely related to changes in the cod fishery, targeting larger NEA cod individuals by using larger mesh sizes in nets as their proportion in the stock increased. This may have affected selectivity on the coastal cod stock in a similar way in areas and time periods where the two stocks overlap. The output from EQSIM and associated reference points are shown in Figure 3.8. B_{lim} and F_{lim} are shown in relation to the SAM estimates of SSB and F_{bar} in Figure 3.9.

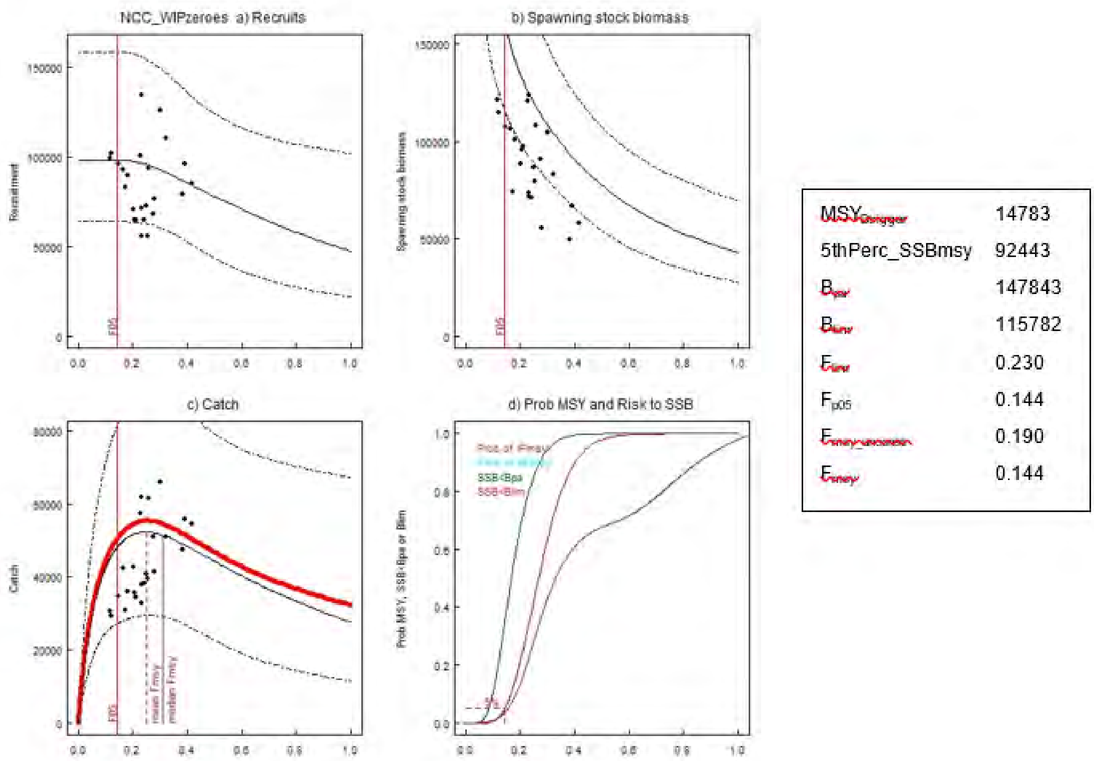

Figure 3.8. Output from the EQSIM simulation. The estimated reference points are shown in the box to the right.

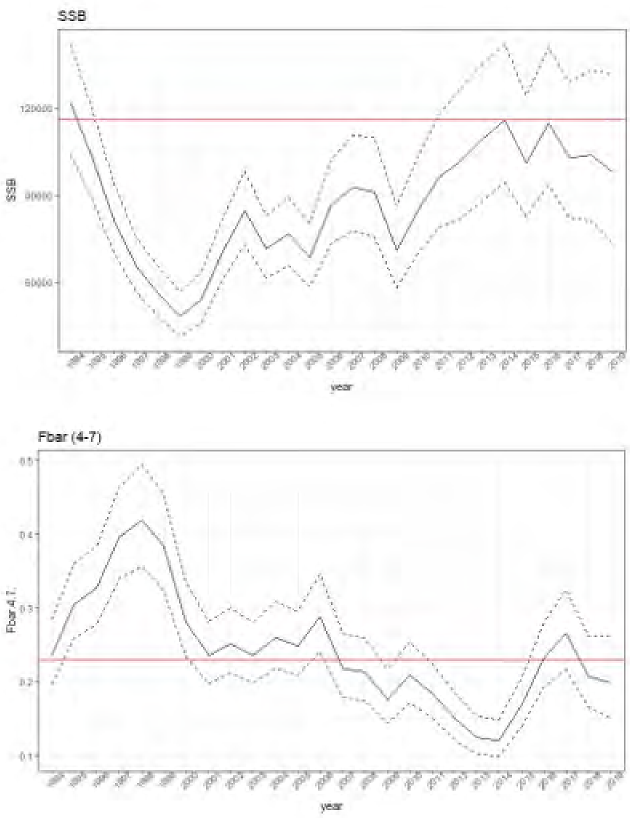

Figure 3.9. SAM estimates of SSB (top) and F_{bar} (bottom) in relation to the reference points B_{lim} and F_{lim} (red lines).

3.7 Future considerations

The benchmark meeting concluded that we have confidence in the new assessment, but because of the particular range of observed SSBs and recruitments it is difficult to estimate reference points. The reported F target should not at this point be considered precautionary for advice. There is a need to develop a harvest control rule for this stock, and potentially a new rebuilding plan. All reference points should be subject to re-evaluation in connection with an MSE.

3.7.1 Management plan and scientific advice

The current management plan for coastal cod applies to the whole stock complex north of 62°N and was put into operation in 2011. The plan specifies the following steps for reducing fishing mortality (F_{bar} 4–7) relative to F_{bar} in 2009 (F_{2009}) in every year when the survey shows a reduced SSB-index relative to the year before:

Action year	**1**	**2**	**3**	**4**	**5**	**6 and later**
Reduction relative to F_{2009}	15%	30%	45%	60%	75%	Keep F at or below 0.1

The rebuilding goal in the management plan is to consider the stock complex restored when the survey index of spawning–stock biomass is > 60 000 t in two consecutive years. This target was the average acoustic survey index of SSB in the years 1995–1998. The survey index has now been revised down to 32 000 t (total area north of 62°N).

The conclusion that F_{bar} should have been reduced by 60% in 2019 relative to 2009 still stands with the revised survey SSB estimate. Since most of the coastal cod biomass and fishery is distributed north of 67°N, we consider the estimated annual F_{bar} from the new assessment model relevant for assessment of F in relation to the reference F_{2009}. Based on the SAM, F_{bar} for the northern component was 13% (uncertainty range 4–21%) higher in 2019 compared to 2009. F_{2009} in the new model is 0.176, below the estimated, but uncertain, F_{lim} (0.230) and above F_{MSY} (0.144).

We stress the need for developing a HCR for this stock, to replace the current management plan as basis for future advice. In order to make the importance of this clear to managers and stakeholders, the benchmark recommends that the section “ICES advice on fishing opportunities” in the advice sheet include the text “ICES strongly recommends the development of a new management plan for this stock, including a full management strategy evaluation”.

The commercial catches of this stock occur as part of a mixed fishery with the NEA cod. The benchmark therefore recommends that the advice sheet include a line in the catch options table showing the expected impact on the coastal cod north of 67°N of the advised catch for NEA cod under the recent catch split between the two stocks. There should be a line of description under the catch option table stating: “An illustrative catch option is provided based on the expected mixed-fishery catch resulting from the advised catch of NEA cod.”

3.7.2 Research recommendations

Several research recommendations were put forward during the benchmark meeting:

- Investigate the age distribution in pelagic versus bottom trawl hauls in the coastal survey – does distribution in the water column vary by age and how does this affect survey indices?

- Establish routines for verifying/classifying uncertain typed otoliths as coastal cod or Northeast Arctic cod using genetics.
- Develop methodology for data collection and calculation of catch quantity in recreational and tourist fishing.
- Extend coastal cod landings statistics back to 1984.
- Continue to work on natural mortality; improving the size-based estimates, looking further into changes in M over time, and exploring other methods of estimation.
- Investigate use of survey data for ages 8–9 weight in stock (possibly also 10+) if/when more data on these ages become available.
- Investigate ways of handling poor catch estimates in SAM – we may get better estimates of recreational catch for recent years once longer time-series of this fishery has been obtained. Should the earlier, more uncertain recreational catches be down-weighted?
- Continue to investigate SAM configurations, particularly the correlation structures.
- Investigate the use of longer periods for recruitment sampling in the short-term forecast.
- Do more work on reference points (via simulation, MSE, etc.)

3.8 Reviewer's comments

The reviewers support the adoption of the proposed SAM model as the basis of ICES advice. For full reviewer comments see Section 6 (3).

3.9 References

Aglen, A., Nedreaas, K., Knutsen, J. A. and Huse, G. 2020. Kysttorsk nord for 62-grader nord – Vurdering av status og forslag til forvaltningstiltak og ny gjenoppbyggingsplan. Fisken og Havet: 2020-2, Institute of Marine Research, Bergen. 64 pp. (in Norwegian – figure legends in English presented as background document to WKBarFar).

Berg, H.S.F. 2019. Estimation of discards of cod (*Gadus morhua*) in Norwegian gillnet fisheries. Master of Science in Fisheries, Biology and Management. Department of Biological Sciences, University of Bergen, June 2019. 71pp.

Berg, H.S.F. and Nedreaas, K. 2021. Estimation of discards in Norwegian coastal gillnet fisheries 2012–2018. Fisken og havet, ISSN:1894-5031, 95 pp. *English summary*.

Dahle, G., *et al*. 2018. Analysis of coastal cod (*Gadus morhua* L.) sampled on spawning sites reveals a genetic gradient throughout Norway's coastline. - BMC Genetics 19: 42.

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4 Norwegian coastal cod (*Gadus morhua*) between 62 and 67°N

Coastal cod south of 67°N was formerly managed together with the coastal cod north of 67°N and has now been proposed to be split as a separate management unit. As highlighted in chapter 3 of this report, this subpopulation represents about 20% of the remaining commercial catches, and is not as consistently covered by the main surveys relevant for monitoring cod. Former management was never based on a validated assessment model and current data availability and quality cannot support a full analytical assessment. It was therefore suggested to promote a data-limited approach to support management of this stock.

The benchmark group evaluated three distinct, albeit interleaved, approaches to assess the status and trends of the coastal cod between 62° and 67°N. All of the approaches relied on data provided through a commercial data self-sampling programme in fleets fishing both NEA and coastal cod. A model of the respective proportions of the two stocks within the catch, aimed at segregating the catch between stocks, was therefore also examined as a prerequisite to further assessment.

4.1 Data

4.1.1 Catch statistics

Revised catch data are available from 1994. The revised catch data include commercial catches and an estimate of recreational catches (Table 4.1). The estimate of recreational catch is a constant catch in tonnes added each year and split by age-based on the age structure in the commercial catches. There is ongoing work to obtain annual estimates of recreational catch for later years. Details on the catch data revision are found in WD-7 and WD-13. We assume that all fish caught commercially are landed, i.e. no discards, as discarding is banned in Norwegian waters. Some minor discards may occur, mainly in gillnet fisheries (less than 5% in weight of total cod catch), where occasionally scavengers reduce the catch quality (Berg and Nedreaas, 2021). The recreational catches include estimates of discards (mainly from catch-and-release by rod and line fishing from boats) for which the assumption is 20% mortality (see WD-13).

Table 4.1. Left - estimated commercial catches of Coastal cod north of 67˚N and between 62-67˚N, and Northeast Arctic cod between 62-67˚N. Right – estimated recreational catches of cod north of 67˚N and between 62-67˚N, all assumed to be coastal cod. Note that an unlikely low share of CC vs NEAC in 2001 commercial landings compared to years before/after was corrected by reassigning catches between CC and NEAC in their average respective proportions in 2000 and 2002.

Commercial catch (in tonnes):				Recreational catch (in tonnes):			
Year	Coastal cod	Coastal cod	NEA cod	Year	Coastal cod	Coastal cod	Total
	N of 67˚N	S of 67˚N	S of 67˚N		N of 67˚N	S of 67˚N	recreational
1994	52 579	6 381	23 430	**1994**	9 144	5 556	14 700
1995	56 907	8 936	16 981	**1995**	9 144	5 556	14 700
1996	41 820	6 207	13 250	**1996**	9 020	5 480	14 500
1997	46 605	4 746	12 695	**1997**	9 020	5 480	14 500
1998	45 462	6 200	9 389	**1998**	9 082	5 518	14 600
1999	38 743	5 522	7 101	**1999**	8 646	5 254	13 900
2000	33 081	5 838	4 329	**2000**	8 460	5 140	13 600
2001	24 470	*5 250*	*3 499*	**2001**	8 335	*5 065*	13 400
2002	32 188	6 937	4 266	**2002**	8 460	5 140	13 600
2003	29 253	8 905	3 943	**2003**	8 646	5 254	13 900
2004	31 198	6 866	3 941	**2004**	8 335	5 065	13 400
2005	30 097	8 005	1 462	**2005**	8 211	4 989	13 200
2006	36 884	8 612	1 175	**2006**	8 087	4 913	13 000
2007	26 200	7 695	2 250	**2007**	8 087	4 913	13 000
2008	27 711	9 889	1 376	**2008**	7 962	4 838	12 800
2009	22 988	7 145	2 474	**2009**	7 900	4 800	12 700
2010	34 804	7 634	2 685	**2010**	7 900	4 800	12 700
2011	27 982	7 128	7 474	**2011**	7 900	4 800	12 700
2012	26 778	8 187	4 942	**2012**	7 900	4 800	12 700
2013	21 376	5 131	8 395	**2013**	7 900	4 800	12 700
2014	22 750	6 244	6 682	**2014**	7 900	4 800	12 700
2015	34 483	5 004	5 424	**2015**	7 900	4 800	12 700
2016	49 503	5 962	2 006	**2016**	7 900	4 800	12 700
2017	54 273	4 159	1 242	**2017**	7 900	4 800	12 700
2018	34 532	4 436	1 822	**2018**	7 900	4 800	12 700
2019	35 861	2 965	1 677	**2019**	7 900	4 800	12 700

4.1.2 Reference fleet

The Norwegian Reference Fleet is a group of active fishing vessels paid and tasked with providing information about catches (self-sampling) and general fishing activity to the Institute of Marine Research. The fleet consists of both high seas and coastal vessels that cover most of Norwegian waters. The High seas Reference Fleet began in 2000 and was expanded to include coastal vessels in 2005 (Clegg and Williams, 2020). The Coastal reference fleet has reported catch per gillnet soaking time (CPUE) from their daily catch operations (WD-17).

These fleets catch cods from both coastal and NEA populations, which can be discriminated based on their otolith shape. Size distribution of individuals is sampled from a subset of fishing events and, within the size samples, individuals are sampled for otolith in a presumably random way. Preliminary exploration of the length composition data however revealed, in some years, a size-biased sampling of individuals used for ageing and stock segregation. This bias therefore had to be accounted for and corrected as a preliminary step to any subsequent size-based analysis.

4.1.3 Annual coastal survey

As highlighted in Section 3.3.2, the main survey covering coastal cod is the autumn coastal survey (Nocoast-Aco-4Q), ran annually in October–November since 1995. It was initially designed as an acoustic survey only and features, since 2003, fixed bottom trawl stations in addition to continuous acoustic registrations. The coverage south of 67°N lacks consistency (weather dependent), with few trawling stations carried out most of the years (Annex WD33) and accordingly few cod caught (maximum 410 a year since 2010, including age 0 cohort). It was hence disregarded for size-based approaches south of 67°N, but biological samples from the whole survey were considered for life history traits evaluation when deemed relevant.

4.2 Evaluated models

4.2.1 Stock segregation – P(coastal) model

In order to determine the origin of cod, we used all data from above 62°N (i.e. ICES Subarea 2.a.2; Norwegian statistical areas 3, 4, 5, 0, 6, 7) with information on otolith type. The probability of a fish caught to be coastal cod (as opposed to NEA cod) was modelled using a Binomial GLM. The covariates area (Norwegian statistical area), year, quarter and gear, all coded as factors, were examined and a model selection performed based on an information theory approach.

The final model configuration retained is (R notation):

```
glm(is_coastal ~ factor(area) * factor(year) +
                 factor(quarter) + factor(gear),
    family=binomial(link = "logit"),...)
```

Equivalent to a model of the form

$$P(coastal\,|\,i,j,k,l) \sim Binomial(\lambda_{ijkl})$$

$$log\left(\frac{\lambda_{ijkl}}{1-\lambda_{ijkl}}\right) = \beta_0 + \beta_{1i}area_i + \beta_{2j}year_j + \beta_{3ij}\left(area_i \times year_j\right) + \beta_{4k}quarter_k + \beta_{5l}gear_l + \epsilon_{ijkl}$$

$$\epsilon_{ijkl} \sim N(0,\sigma) \qquad \text{iid}$$

where i, j, k and l are the factor indices of area, year, quarter and gear respectively.

The modelled proportions of coastal cod per area and quarter are represented in Figure 4.1. Further use for the elaboration of the CPUE index specifically focuses on area 6 and 7 (South of 67°N) and quarter 3 and 4 (bottom right corner of the figure) because it is believed that this is the best data to inform about coastal cod status in this area.

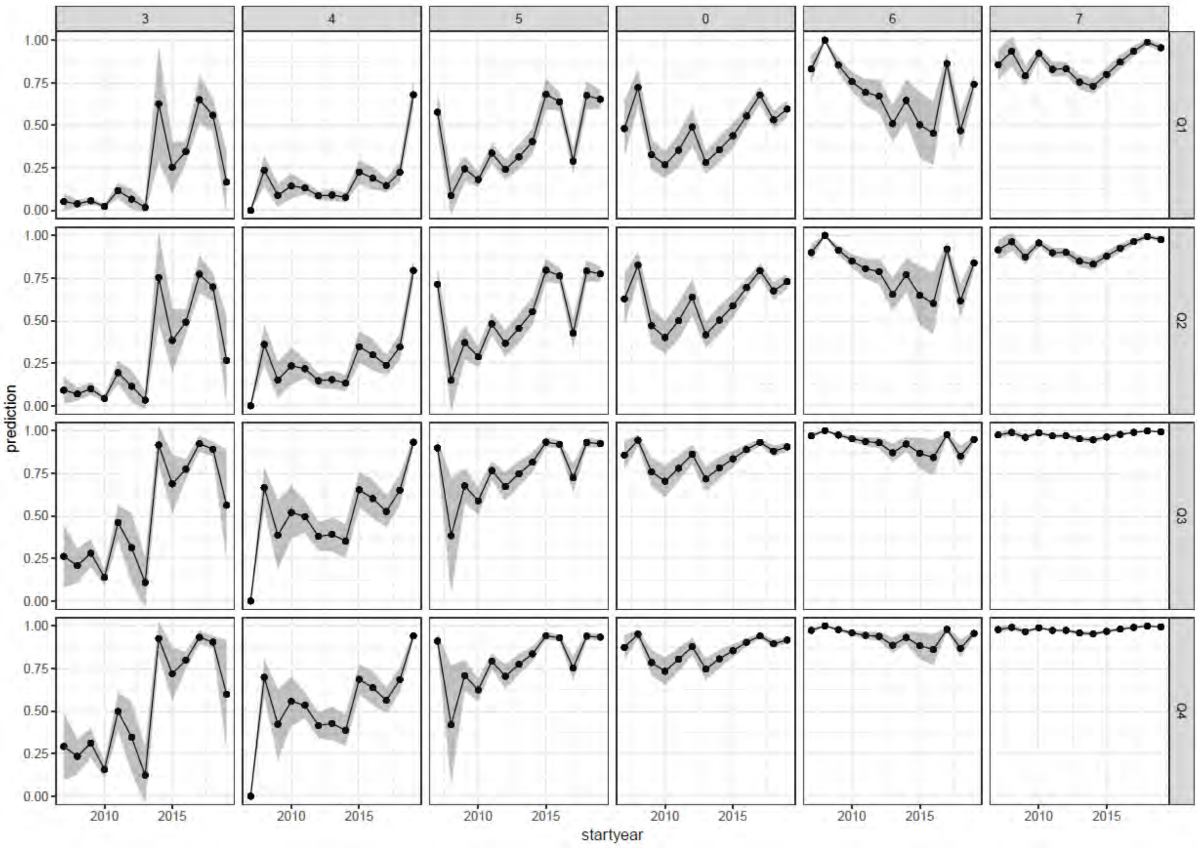

Figure 4.1. Predicted proportions of coastal cod in the coastal reference fleet catches by statistical area and quarter during 2007–2019 based on otolith classification using ALL otolith categories,(i.e. including uncertain classifications). The increasing year trend in the northern areas (3, 4 and 5) is also related to changes in fishery regulations allowing more cod to be caught during autumn months when most of the cod on the coast is coastal cod. The shaded polygon is the 95% confidence interval for the prediction.

Individual length information was intentionally ignored in this first model as of no practical use for the CPUE index calculation: only part of the sampling data contained individual size information and such a model would not have been applicable for resolving stock proportions in catch data at the catch sampling scale. For the size-based LBSPR model, however, stock discrimination within the data sampled for size was required, and an alternative model including fish length as a covariate considered. The final model, retained for this purpose after a similar selection process, was a GAM with a smoother on individual length (default smoother in the R package mgcv) which improved the model fit substantially compared to without size covariate (delta AIC > 2000). The selected model was:

```
gam(is_coastal ~ factor(area) * factor(year) + s(length) +
                 factor(quarter) + factor(gear),
    family=binomial(link = "logit"),...)
```

and was fitted using the R package mgcv. A representation of the model output, limited to areas 6 and 7 is presented in Figure 4.2. It highlights that the probability, of an individual caught in these areas, to be a coastal cod increases in the course of the year and decreases with individual size. The very wide uncertainty in area 6 in 2008 reflects a scarcity of data and has no practical consequences as only data from 2010 onwards are used in the subsequent size-based approach.

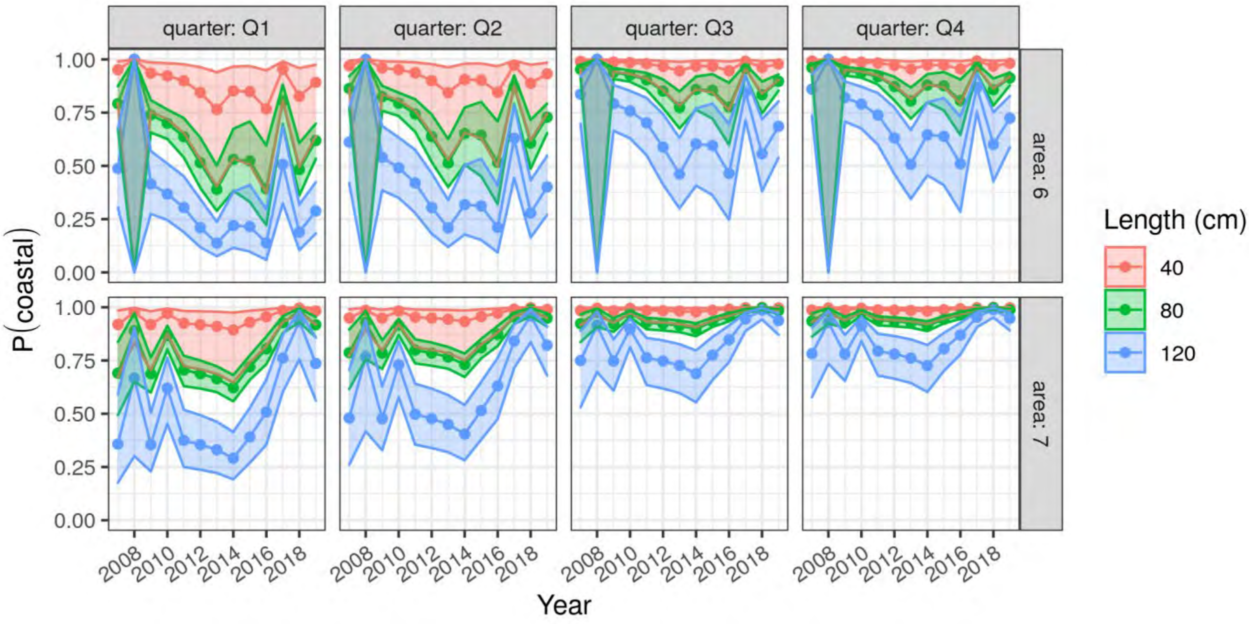

Figure 4.2. Predicted proportions of coastal cod at different sizes in the coastal reference fleet catches by statistical area and quarter during 2007–2019 based on otolith classification using all otolith categories (i.e. including uncertain classifications). The shaded polygon is the 95% confidence interval for the prediction.

4.2.2 Standardized CPUE index

Raw CPUE data are seldom proportional to population abundance as many factors (e.g. changes in fish distribution, catch efficiency, effort, etc.) potentially affect its value. Therefore, CPUE standardization is an important step that attempts to derive an index that tracks relative population dynamics. Standardised CPUEs were calculated as:

$$Standardizedeffort(gillnetday) = gearcount \times soakingtime\ (hours)/24\ hours$$

$$CPUE(pergillnetday) = \frac{catchweight}{standardizedeffort} \qquad \text{equ. 4.1}$$

for all cod (coastal and NEA as a whole), limited to areas 6 and 7 and quarter 3 and 4. Further data filtering was performed to remove erroneous data point and any gear code with less than three observations.

The standardised CPUE was modelled using a general linear mix model approach in R (package glmmTMB). The selected model (here in its R formulation) includes mixed effects on existing combinations of area and years (area_year) as well as quarter and year (quarter_year):

```
glmmTMB(log(cpue_all) ~ factor(startyear)
           + factor(area) + factor(gear) + factor(quarter)
           + (1|area_year) + (1|quarter_year),
       family = gaussian, ...)
```

Details of modelling choice motivations, model selection and validation are given in Annex 2 WD 17.

The standardized coastal cod index ($CPUE_{coastal\ cod}$) was calculated as:

$$CPUE_{coastalcod} = P_{coastal} \times CPUE_{cod}$$

Where $P_{coastal}$ is the predicted proportion of coastal cod in the catch based on the output from the binomial model presented in Section 1.2.1, and $CPUE_{cod}$ the predicted cod (of both ecotypes) CPUE described in equ. 4.1 of this section.

The variance of $CPUE_{coastal\ cod}$ was calculated as:

$$V(CPUE_{coastalcod}) = \left(\hat{P}_{coastal}\right)^2 V(CPUE_{cod}) + \left(\widehat{CPUE}_{cod}\right)^2 V(P_{coastal})$$

The resulting standardised CPUE index series is represented in Figure 4.3. A composite index averaged over quarters (equal weights) and areas (weights in proportion of the respective surface areas within 12 NM of statistical areas 6 and 7) was also produced and is represented in Figure 4.4.

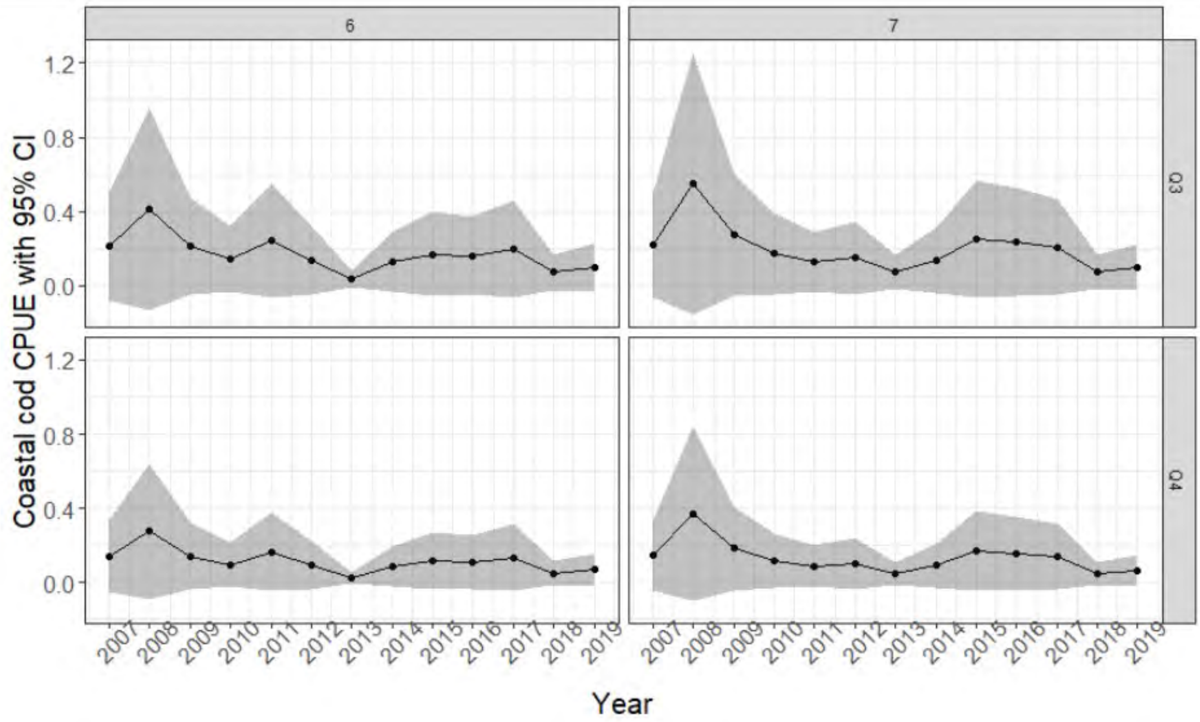

Figure 4.3. Standardized CPUE index for coastal cod in area 6 and 7 during quarters 3 and 4, between 2007–2019. The grey shaded polygon represents the 95% confidence interval (calculated using the approximation: mean +/- 1.96 std.; negative values are therefore introduced in the plot as an artefact of this procedure).

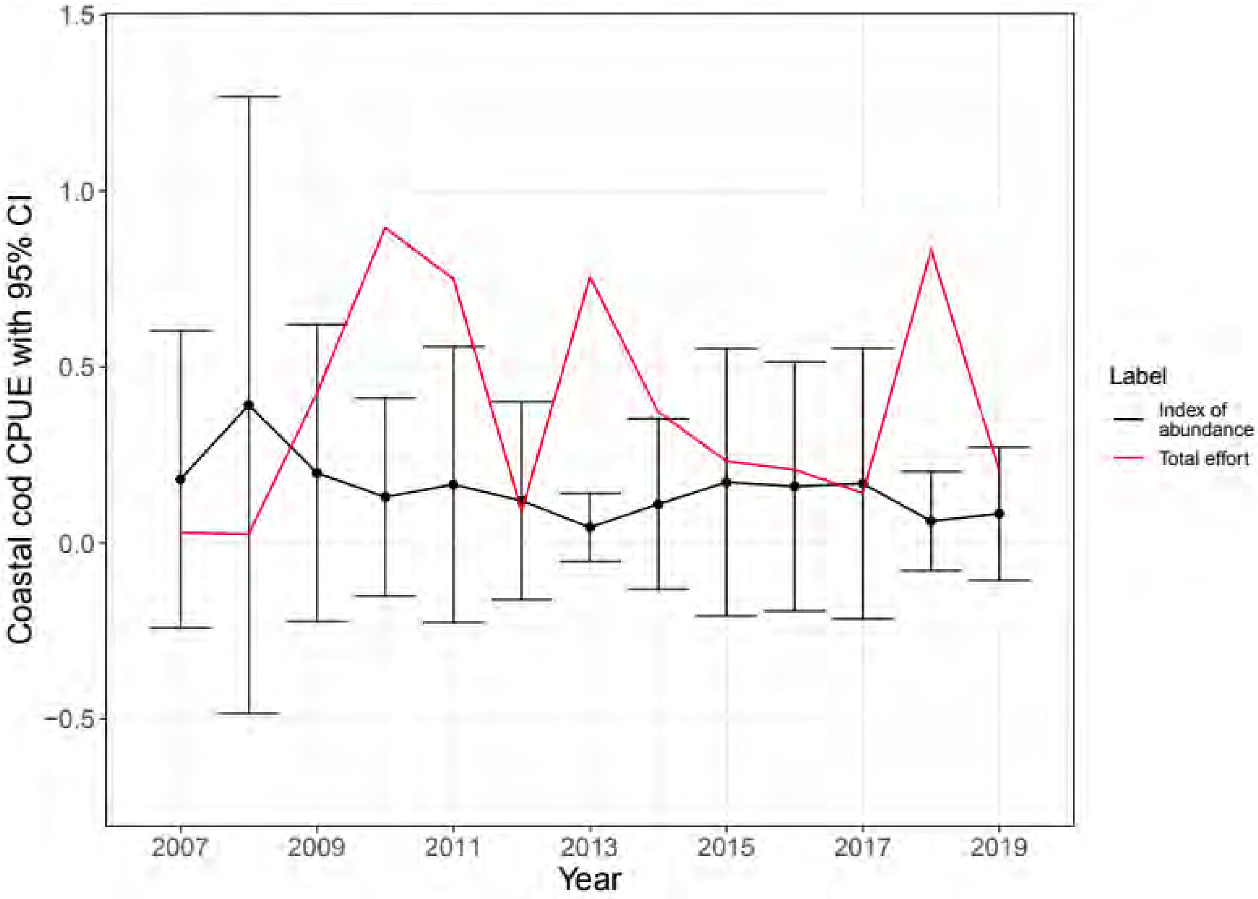

Figure 4.4. Composite standardized CPUE index for coastal cod in area 6 and 7 during quarters 3 and 4, between 2007–2019. 95% confidence interval (calculated using the approximation: mean +/- 1.96 std.; negative values are therefore introduced in the plot as an artefact of this procedure) are given by error bars.

4.2.3 Surplus production model – SpiCT

Attempts were made to fit a stochastic surplus production model in continuous time (SpiCT; Pedersen and Berg, 2016) using the composite standardized commercial CPUE as a biomass index and catches allocated to the coastal cod between 62 and 67°N. Convergence issues were experienced using the full catch series (1994–2020), likely due to the biomass index only partially overlapping the catch series (from 2007 onwards). The model fitted with a trimmed catch series (2007–present) exhibited very wide confidence intervals and pronounced sensitivity to priors such as on initial depletion, even while forcing a Schaefer model (production curve shape parameter n=2). This was most likely due to the time-series being too short and lacking contrast, as both catches and CPUEs exhibited a near-steady decline over the 13 years period considered. These all together rendered the model useless for management purpose.

Further attempts to fit the model with the full catch series by using both the commercial CPUEs and an acoustic index based on the coastal survey data (recalculated for commercial size only; >40 cm) as biomass indices, failed to produce consistent model outputs. The reason lies in the survey index being dominated by noise, as the survey has an uneven coverage among year (annexe WD33) and the number of stations and cod caught south of 67°N is low. The consistency between indices was found to be accordingly very poor. WKBarFar assessed that there was no rational for using a trimmed survey index in order to train the model in fitting earlier catches, and that the coastal survey index should be disregarded all together for the assessment of coastal cod south of 67°N. Recommendation was formulated to re-evaluate SPiCT as a basis for management when the standardised CPUE series gets longer.

4.2.4 Stochastic LBSPR

The length-based spawning potential ratio (LBSPR; Hordyk *et al.*, 2015a; 2016) was developed to help the management of data-poor fisheries based on a well-documented theoretical background (Hordyk *et al.*, 2015b; Prince *et al.*, 2015). It depicts the hypothetical size distribution of the commercial catches, under given exploitation levels, of a population at equilibrium based on the knowledge of its life history.

Based on a limited set of life-history traits and ratios, the model can estimate the level of depletion likely to result in the observed size distribution in catches, and derive quantities linked to the exploitation pattern (selectivity ogive) and intensity. In particular, the model estimates F/M, the ratio of fishing to natural mortality, and the spawning potential ratio (SPR) representing the ratio of exploited over virgin spawning biomass from a per recruit perspective. Additionally, if information on the stock–recruitment relationship steepness is available, MSY reference points such as F_{MSY}/M or SPR_{MSY} can be derived (Brooks *et al.*, 2010; Hordyk *et al.*, 2015a).

The model is equilibrium based (constant recruitment and mortality-at-size; including fishing mortality) and assumed that (*i*) the length composition data in the catch are representative of the population size distribution and (*ii*) that the selectivity is asymptotic following a logistic function. As for the parametrisation, it does not require knowledge of the natural mortality rate (M), but instead uses the ratio of natural mortality and the von Bertalanffy growth coefficient (k) (M/k), which is believed to vary less across stocks and species than M (Prince *et al.*, 2015). Other important input parameters are the asymptotic length, L_∞, and – for the estimation of the SPR – the maturity ogive ($Lm_{50\%}$, $Lm_{95\%}$). The model accounts for the effect of inter-individual variability in growth through a coefficient of variation of L_∞, but this is often arbitrarily fixed due to lack of information (Díaz *et al.*, 2016; Hordyk *et al.*, 2016).

Given the uncertainty in parameters and the demonstrated sensitivity of the model to input parameters (Hordyk *et al.*, 2015b, 2015a), we implemented a stochastic LBSPR approach similar on the principle to the one developed for Monkfish within the Arctic fisheries working group (ICES, 2020). Differences with this former approach include variations in the parametrisation of random inputs, and the inclusion, in our model, of bootstrapped size distributions to account for uncertainty in the observation of length compositions.

4.2.4.1 Parametrisation, life-history traits estimation

Growth parameters were fitted using the reference fleet self-sampling data for those individuals identified as coastal cod. Size selective sampling of age data is known for introducing biases in the growth parameter estimates (e.g. Taylor *et al.*, 2005; Troynikov and Koopman, 2009; Gwinn *et al.*, 2010; Perreault *et al.*, 2019; Hilling *et al.*, 2020). We used a non-least squares approach to fit von Bertalanffy parameters on length and decimal age data (t_0 borrowed from coastal cod north of 67°N), while correcting for biases using composite weights based on the product of:

1. calibrated weights (size-selective ageing among individuals sampled for size; Perreault *et al.*, 2019) and
2. weights correcting for size selectivity-at-age in the catch (loosely based on model 1 in Taylor *et al.*, 2005), using selectivity parameters estimated using LBSPR and parameters borrowed from coastal cod North of 67°N.

Residual patterns were observed in the model produced (Figure 4.5), but in accordance with expectations while correcting for size selective sampling biases. No substantial difference with the asymptotic length in the northern stock was found, while k was significantly higher in the South, consistent with previous reports of faster growth at lower latitude (Berg and Albert, 2003).

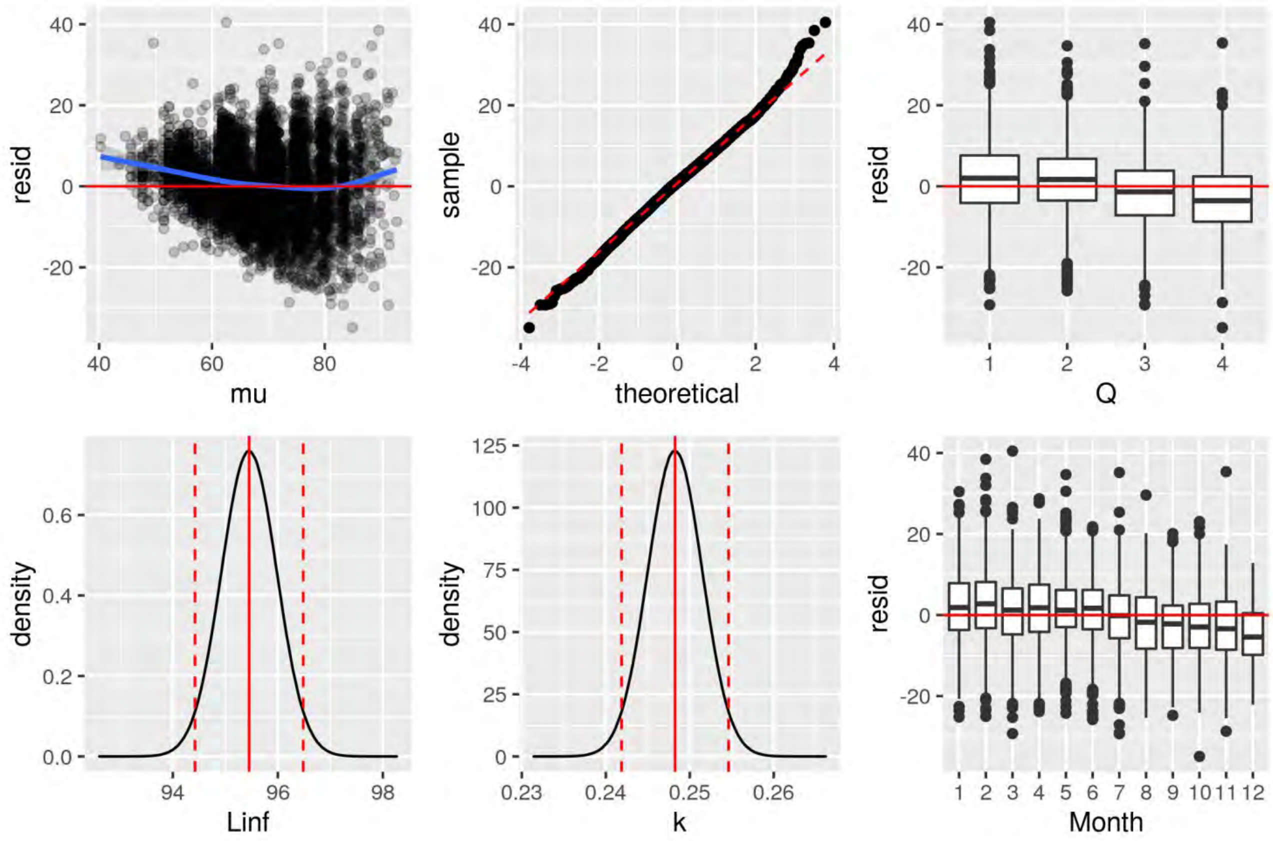

Figure 4.5. Von Bertalanffy growth function fitting (non-linear least squares) diagnostics and parameter (Linf, k) distributions estimated for coastal cod south of 67°N. The residual pattern observed in the top-left panel is consistent with expectations following correction for size-selective sampling bias.

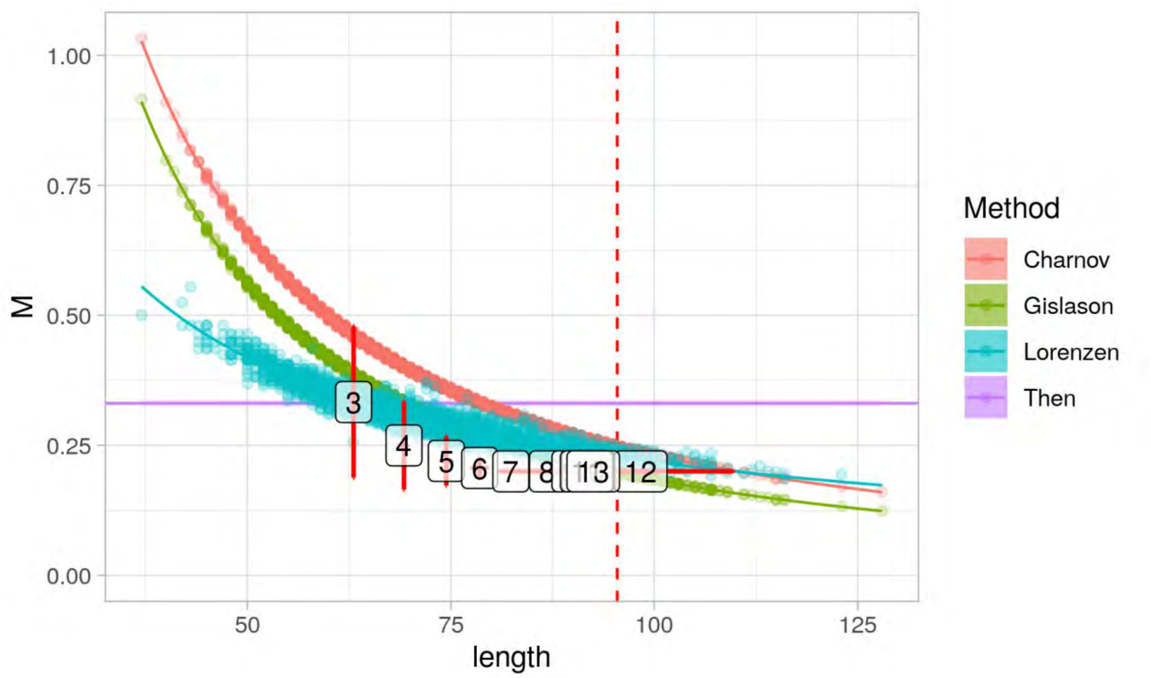

Figure 4.6. Natural mortality (M) at size of coastal cod south of 67°N, following for methods based on life histories. Based on fitted growth parameters and individual size and weights resampled from the reference fleet data. Overlaid labels and error bars (95% CI) represent mortality-at-age estimated based on stomach contents (cannibalism) for the partially sympatric NEA cod (2010–2020). Sizes-at-age are borrowed from the coastal cod south and are likely underestimated for younger ages.

One of the most critical parameters for the performance of LBSPR is M/k. Here we had first-hand growth parameter estimates but no *a priori* information on M/k in coastal cod. Estimating M based on life history was therefore favoured, and four methods tested: one giving a constant M (Then *et al.*, 2015, 2018b) and three size varying M estimates (Lorenzen, 1996; Gislason *et al.*, 2010; Charnov *et al.*, 2013). SPR estimates based on these four different M were shown to have different absolute values but fairly similar trends. Among the four options examined for the parametrisation of natural mortality, the size varying M following Lorenzen (1996) was retained based on its consistency with cannibalism-driven mortality in the partially sympatric NEA cod (Figure 4.6). It also provides the SPR and F/M estimates the closest to a M=0.2 scenario, while there is consensus that it represents a more realistic alternative than the later.

Maturity was estimated for the whole autumn coastal survey data north of 62°N, on account of scarcity of biological cod samples for the area between 62 and 67°N alone. For consistency with the choices made for the northern stock (Section 3.3.3), resting individuals (stage 4) where included in the mature fraction. The maturity parameters (length at 50% and 95% maturity) were estimated by fitting a binomial GLM on yearly bootstrapped maturity data with covariate length (500 resampled datasets). The yearly (2010–2019) parameter distributions are shown in Figure 4.7 and do not exhibit any noticeable trend over time. For the later parametrisation of the stochastic LBSPR model, pairs of Lm_{50} and Lm_{95} parameters estimated from the same bootstrapped dataset and year were drawn together to preserve the correlation between the two parameters.

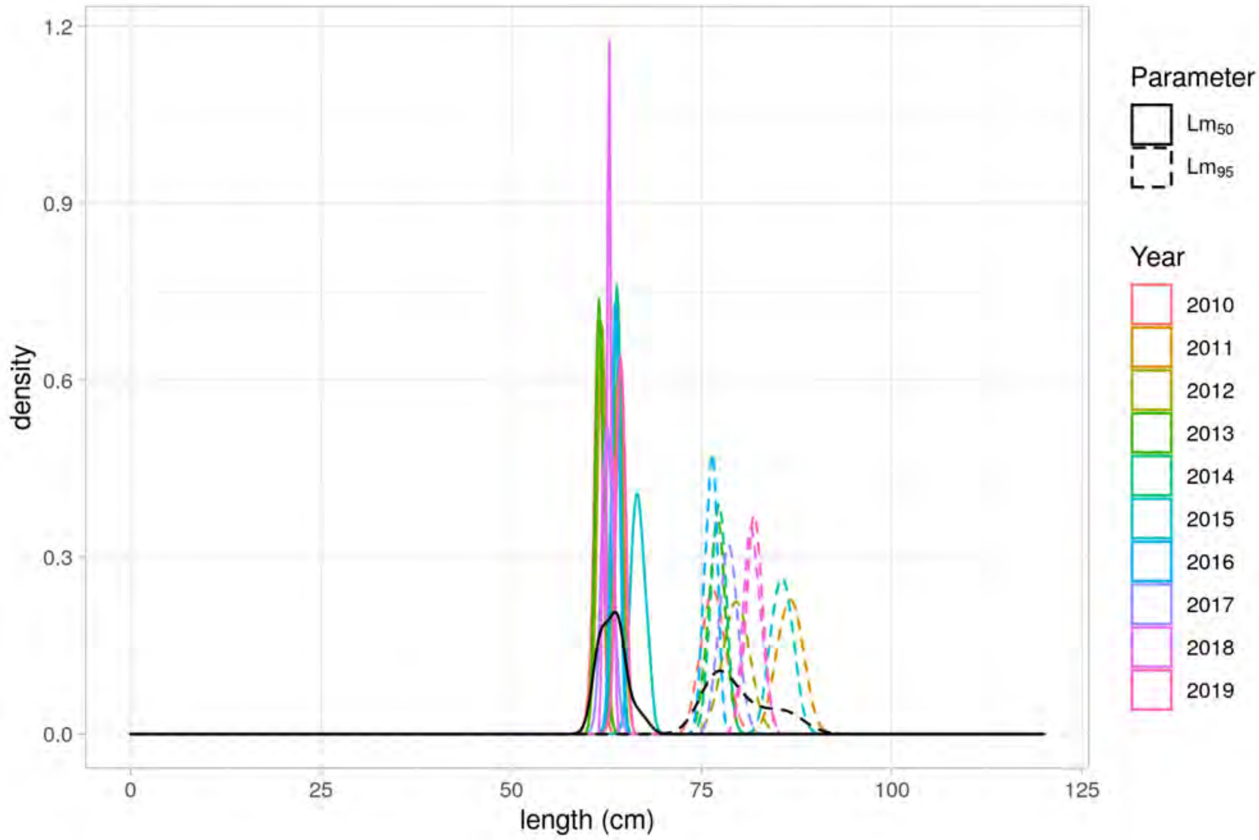

Figure 4.7. Maturity ogive parameters per year estimated for coastal cod (all data north of 62°N). Lm_{50} and Lm_{95}: length at respectively 50% and 95% maturity. Based on bootstrapped data from the coastal survey and fitted using a binomial GLM. The black lines represent the overall distributions of the parameters.

Table 4.2. Parameters used to set up the stochastic LBSPR approach and their value (including uncertainty). Parameters in bold are the inputs of the LBSPR model. Other parameters not detailed here were left to their default values.

Parameter	Mean value (sd)	Description, comment
M	0.228 (0.0012)	Natural mortality (year^{-1}) at asymptotic length (Linf). Fitted from size varying M estimates based on resampled reference fleet commercial sampling data following Lorenzen (1996).
Mpow	0.939 (0.0042)	aka exponent c, equ. 17 in Hordyk *et al.* (2016): parametrisation of the size varying mortality in LBSPR. Fitted from size varying M estimates, following Lorenzen (1996), based on resampled reference fleet commercial sampling data.
k	0.248 (0.0033)*	growth coefficient from a von Bertalanffy growth function.
M/k	0.919 (0.0078)	M/k at L_∞, derived from the above estimates of M and k.
Linf	95.45 (0.528)*	Asymptotic length L_∞ (cm), as defined in a von Bertalanffy growth function.
t_0	-0.0388	Theoretical time (year) where length = 0 in a von Bertalanffy growth function. Not a LBSPR parameter *per se* but used for the estimation of k and Linf above parameters. Estimate borrowed from the coastal cod North of 67°N (EP method).
CVLinf	0.155 (0.0006)	Coefficient of variation of asymptotic length. Encompass all inter-individual growth variability in LBSPR. The values used are the CV of size-at-age, and its uncertainty, estimated for the coastal cod North of 67°N (EP method). Estimated and randomly generated on the log scale (mean = -1.862; sd = 0.0039).
LM50	63.36 (1.688) †	Length (cm) at 50% maturity. Estimated from resampled coastal survey data (2010-2019) using a binomial glm.
LM95	79.92 (3.924) †	Length (cm) at 95% maturity. Estimated from resampled coastal survey data (2010-2019) using a binomial glm.

*** randomly generated preserving the correlation structure between k and Linf using a multinormal distribution.**
† pairs (LM50, LM95) estimated from a same bootstrapped dataset and year drawn together to preserve the correlation between the two parameters and avoid using a parametrisation based on the distribution of ΔLm = LM95 - LM50.

Further details regarding the life-history traits estimation methods and rationales for choosing them are given in Annex 2 WD 16.

The LBSPR model was fitted on 1000 bootstrapped size composition data and parameter sets. While input parameters were randomly generated/drawn as per Table 4.2, the generation of the randomized datasets was two-fold:

1. Random attribution of unclassified individuals between coastal and NEA cod, based on the size-based stock segregation model (Section 1.2.1) and using a binomial random generator.
2. Bootstrap of the length composition within years.

For each of the 1000 randomized data and parameter set, SPR, F/M and the selectivity parameter $SL_{50\%}$ and $SL_{95\%}$ were estimated and their resulting distributions evaluated.

4.2.4.2 Stochastic LBSPR results

Using the Lorenzen's (1996) M estimate, the mean SPR fluctuates between 20 and 30%, with an overall downward trend (Figure 4.8), which places it below the target values (30–40%) and – at the end of the series – just at the limit reference point 20%, generally accepted in the absence of further information on the stock dynamics (Prince *et al.*, 2020). The relative fishing mortality F/M is estimated above 1 and follows an opposite upward trend (Figure 4.9). The decrease in the spawning potential ratio is concomitant with a decline of size selectivity in the fleet revealed by reduction of both length at 50% and 95% selectivity (Figure 4.10). These all together depict a somewhat depleted and worsening stock status.

In the absence of clear information on the stock–recruitment relationship (see northern stock, Section 3.6), more legitimate reference point cannot be estimated and even a SPR of 30% should be considered as a potentially non-precautionary level, and SPR=40% preferred (Clark, 2002; Hordyk *et al.*, 2015a).

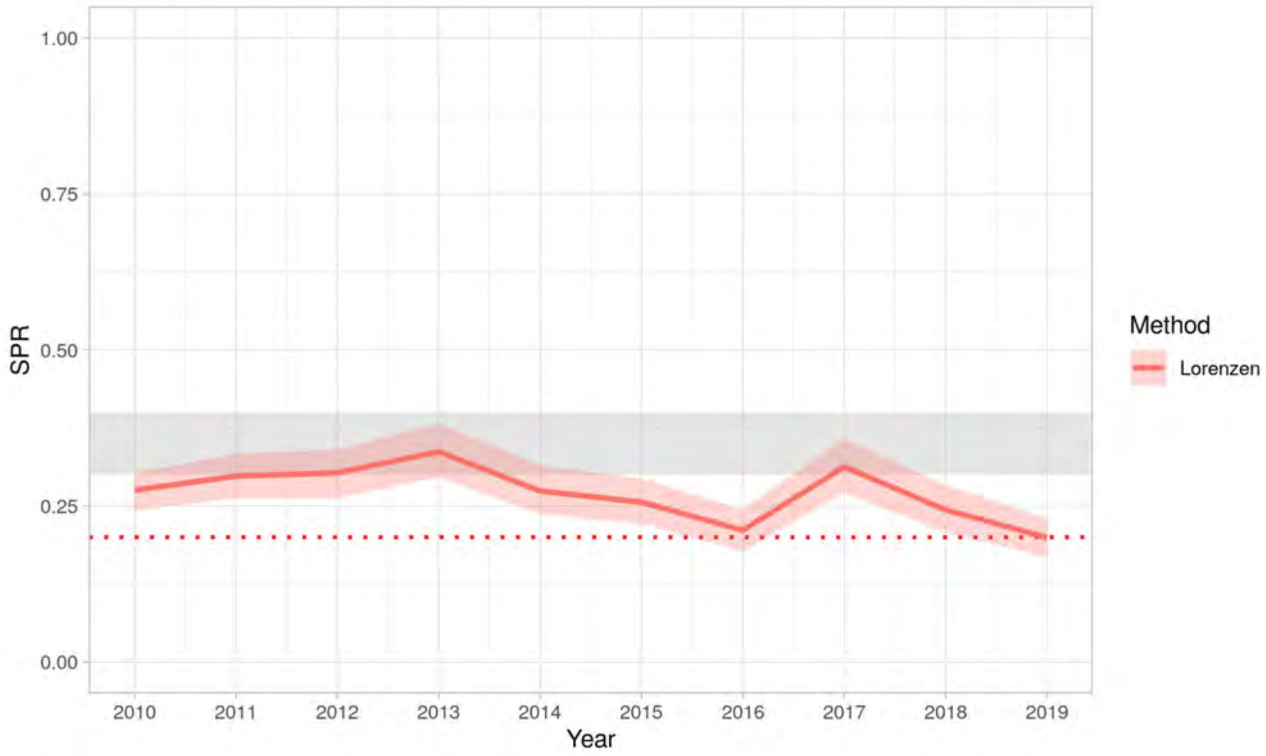

Figure 4.8. Estimated spawning potential ratio (SPR) per year for coastal cod south of 67°N. Mean (solid line) and confidence intervals (shaded red area, 95% IQR), based on the stochastic LBSPR. The grey shaded area delimits the SPR30%–40% zone (common targets) and the dotted horizontal line the SPR20% limit reference point (Prince *et al.*, 2020).

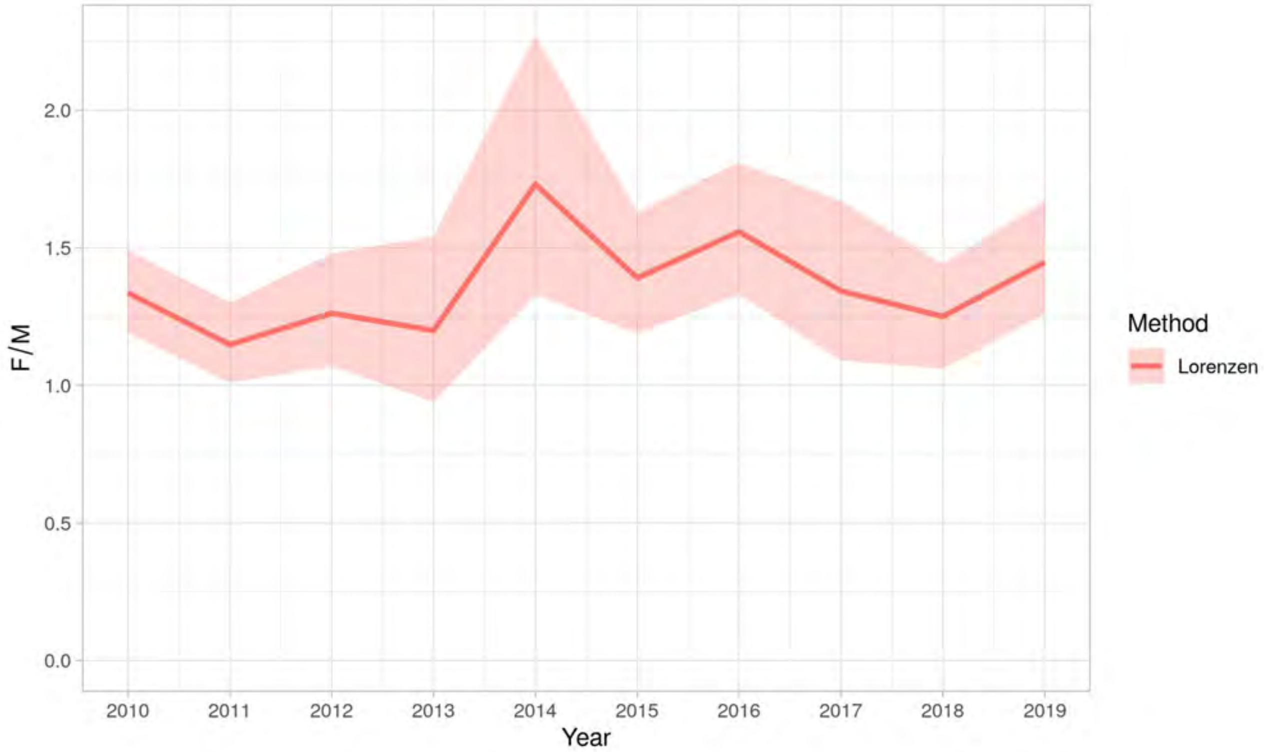

Figure 4.9. Estimated fishing mortality, relative to natural mortality (F/M) per year for coastal cod south of 67°N. Mean (solid line) and confidence intervals (shaded red area, 95% IQR), based on the stochastic LBSPR.

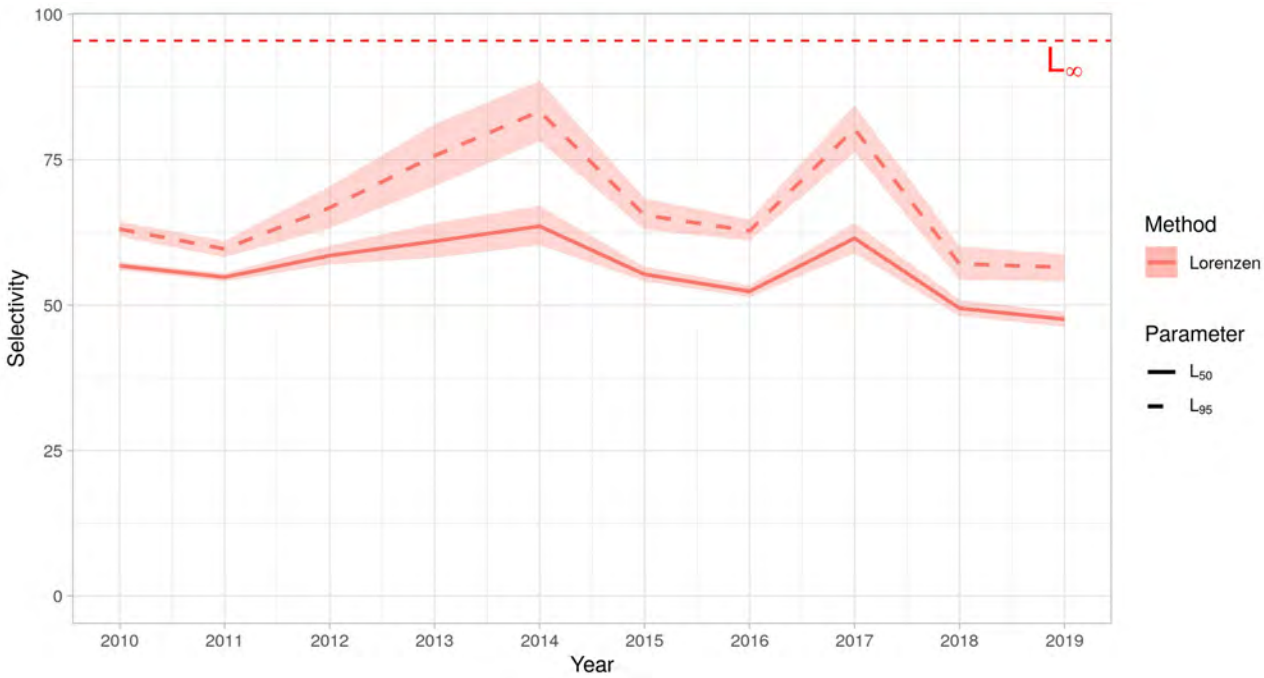

Figure 4.10. Estimated selectivity ogive parameters (size at 50% and 95% selectivity) per year for the gillnet fisheries exploiting coastal cod south of 67°N. Mean (solid and dashed lines) and confidence intervals (shaded red area, 95% IQR), based on the stochastic LBSPR.

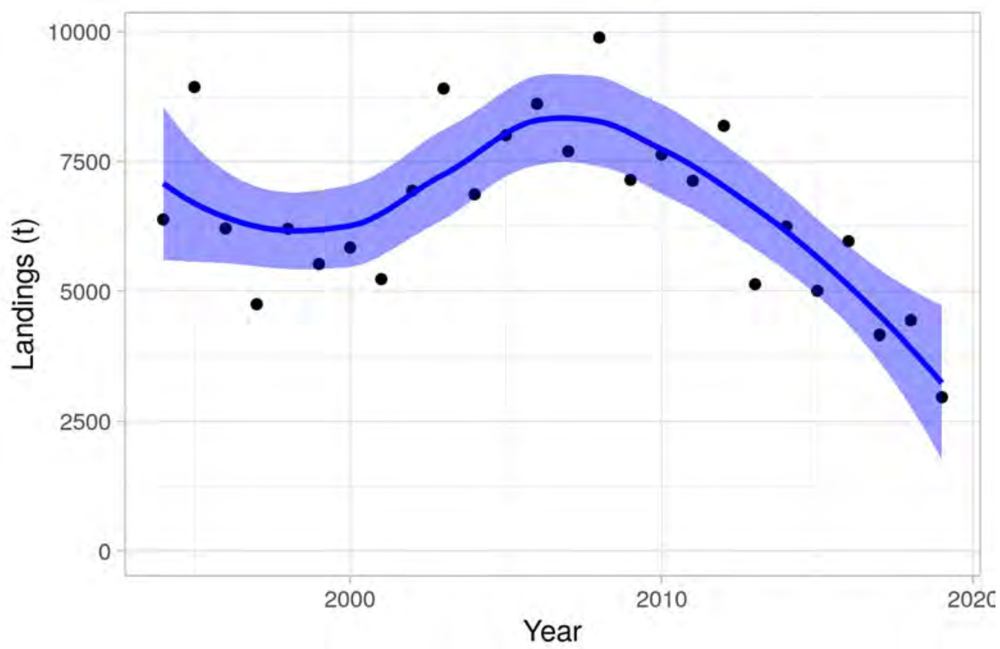

Figure 4.11. Commercial landing per year (tonnes) estimated for coastal cod south of 67°N. Trend based on a GAM smoother.

4.2.4.3 Reflection on assumptions viability

One of the key assumptions of LBSPR is that the population is at equilibrium. Whether the necessary deviations from this assumption lie in a range that does not unreasonably impair the performance for management purpose should ideally be tested using a simulation framework (Chong *et al.*, 2020). This was not done here due to time constraints and the expert group sought for indirect evidence of strong violations instead.

Catches over the last decade have been declining (Figure 4.11) but without strong interannual variations around the trend, which indicates some steadiness in the exploitation. Some years however stand out when it comes to selectivity within the gillnet fisheries (Figure 4.10). 2013–2014 and 2017, for instance, exhibit a flatter selectivity (higher L_{50} and larger L_{95}-L_{50} difference) which will promote an immediate overestimation of the SPR on those years by assuming (under the equilibrium assumption) a larger portion of the SSB to be unaffected by fishing than actually is. Those years with flatter selectivity should therefore be interpreted with extra caution as the expected bias is not conservative. Trends and stock status were confirmed using the size-based indicator $L_{max5\%}$, less sensitive to changes in selectivity, and its corresponding $L_{max5\%}^{SPR=40\%}$ reference point (Miethe *et al.*, 2019), indicating that these variations in selectivity are likely not affecting the overall picture.

Another key assumption of the model, as formulated in the LBSPR package, is asymptotic selectivity. We checked the absence of obvious dome-shaped selectivity by comparing the right side of size distributions in commercial catches and the coastal survey. $L_{max5\%}$, which gives an indication of where the right side of the size distribution stands, did not differ significantly between the two data sources when comparing distributions estimated from bootstrapped data. This cannot however rule out the scenario of a similar dome-shaped selectivity / catchability in both data sources.

On this basis, the approach was accepted as the best indication of the stock status, with nevertheless the recommendation of careful interpretation given possible shortcomings and further investigation of the equilibrium assumption validity using a simulation framework (MSE).

4.3 Recommended assessment and management strategy

Based on evaluations of the models and current ICES practices regarding management of data-limited stocks, and in particular the lack of formal recommendations for the translation of the LBSPR model outputs in harvest control rules, WKBarFar formulated the following recommendations:

- The SpiCT model, based on a short and still too little informative stock index time-series, is not fit for purpose yet. It should however be re-evaluated in the future as the CPUE series gets longer.
- There is no formal framework, accepted by ICES, to formulate quota advices based on LBSPR only. The approach is therefore not recommended for this purpose.
- The standardized commercial CPUE index was accepted by the data evaluation WK as the best information regarding abundance trends. It should therefore be used to provide management advice based on a "2 over 3" rule.
- LBSPR is deemed valid, and the best information at hand regarding the status of the stock. Its use is recommended to indicate whether a 20% precautionary buffer needs to be triggered. The exact reference points still have to be agreed upon.

4.3.1 Research recommendations

A non-restrictive range of research recommendations was formulated:

- Fisheries statistics:
  - methodology for data collection and calculation of catch quantity in recreational and tourist fishing;
  - extension of coastal cod landings statistics back to 1984;
  - establish routines for classifying uncertain typed otoliths as coastal cod or northeast arctic cod using genetics;
  - methodology for calculating survival upon post-release;
  - methodology for calculating other mortality ("natural");
- Standardised CPUEs:
  - further refinement of the data to use;
  - collecting information such as species composition of the catch. Such information could be very valuable in order to account for targeting behaviour that obviously affect a multispecies fishery (Winker *et al.*, 2013);
  - think about the approach of Thorson *et al.* (2016) and how it could potentially be applied using the reference fleet data;
- LBSPR:
  - given the sensitivity of the approach to the M/k parameters, it is recommended to keep looking into the parametrisation of M in particular;
  - validity of assumptions and performance of the model for management of coastal cod should be further investigated using a MSE approach;
  - comparison with other size-based approaches with different assumptions (e.g. MLZ; Then *et al.*, 2018a) was suggested by external experts invited to contribute but was not achievable in the allotted time and should also be considered for future developments.
- SpiCT:
  - reconsideration and refinement of the model while the standardised CPUE series gets longer are advised.

4.4 Reviewers comments

The reviewers support the analysis that no viable analytical model presented that could form the basis of ICES advice. For full reviewer comments see Section 6.

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5 Ling

5.1 Issue list

Ling 27.5b has never been benchmarked before! An exploratory age-based assessment of ling 5b has been presented to the WGDEEP for several years. Currently, this stock is classified as data-poor (DLS method 3.2) that is only based on the Faroese summer groundfish survey, i.e. no age data are used in the assessment.

In WGDEEP 2019, an exploratory assessment of ling 5b was done by using the age-based model SAM in stockassessment.org (lin5b_2020). Ling 5b is likely to have enough data to propose an ICES category 1 framework, but the quality of the proposed assessment needs to be reviewed. So, the goals of the benchmark included 1) reviewing the input data to an age-based assessment (SAM), 2) reviewing the settings of SAM and 3) calculate reference points.

5.2 Evaluation of data

A summary of agreed background data is presented in Appendix 1, and a description of the Faroese ALK-program in Appendix 2 (both appendices found in Annex 2: Working documents.)

5.3 Stock assessment

Prior to the WKBARFAR benchmark this stock was under ICES 3.2 rule, where the assessment type was a survey trend-based assessment (ICES, 2019) using a survey biomass index (kg/hr) from the Faroese summer groundfish survey. There was only exploratory age-based assessment using SAM presented in the WGDEEP report (ICES, 2020).

5.3.1 Assessment methods

At the WKBARFAR benchmark 2021, the suggested age information was adopted and included in the assessment and a Category 1 approach was conducted using the SAM model (See stock annex and Appendix 1). Input in SAM consisted of the catch and weight-at-age 3 to 12+ from 1996 to 2020. Maturity-at-age was set to constant values for the whole period based on the Faroese survey data. The natural mortality was set to 0.15.

The age-disaggregated tuning series consisted of the Faroese summer survey, ages 3 to 11 years (1996–2020) and the Faroese spring survey, ages 4 to 11 years (1998–2020) (Appendix 1).

Several exploratory assessments were carried out on stockassessment.org (Ling5b-001 to Ling5b-005). The data and settings of Ling5b_002 were agreed as the final run by WKBARFAR (Stock Annex).

Ling5b-001: This assessment was mostly based on the data presented at the December 2020 data workshop. The only exception was updated figures for 2020 (cn, cw, sw with all sample data and preliminary catch of 8764 tons). Here, mostly default settings were used. However, F for ages 6 to 10 was used instead of the default and the program setting $keyVarObs was changed for ages 3 and 4 in the tuning series.

- This version of the assessment was not accepted because of two outliers of age 3 in summer survey tuning series in year 2020 and 2019.

Ling5b-002: Same as Ling5b-001, but here the above mentioned two outliers were corrected by borrowing data from four stations in the summer survey 2018 (all ages changed).

- **This version of the assessment was adopted as the final run**. The correction helped stabilize the catch in numbers and the variances in the recruitment results were smaller.

Ling5b-003: Same as Ling5b-001, but corrected two outliers in age 3 in 2020 and 2019 summer survey with NA's for age 3 in 2020 and 2019 (only age 3 changed).

- This version of the assessment was not adopted. The results were very similar to 002, but had higher variance in recruitment.

Ling5b-004: Added a third tuning series with catch in tonnes (1955–1995, not age-aggregated).

- This version of the assessment was not adopted, but gave useful information about the overall stock history. The results were very similar for the period with age distribution, but the model had some technical difficulties in the retrospective pattern.

Ling5b-005: Used spring survey weights-at-age as stock weights instead of using catch weights.

- This version of the assessment was not adopted due to the limited amount of data in the spring survey. Only age data from 2013 to 2020, from 1998 to 2012 the age data were "borrowed" and from 1996 to 1997 an average for the period 1998–2020 was used.

The results and diagnostics of the agreed run Ling5b_002 are presented in Tables 5.1–5.3 and Figures 5.1–5.6.

Table 5.1. Estimated recruitment, spawning–stock biomass (SSB), and average fishing mortality.

Year	R(age 3)	Low	High	SSB	Low	High	Fbar(6-10)	Low	High	TSB	Low	High
1996	1609	1244	2081	18210	15068	22006	0.366	0.259	0.517	29077	24628	34330
1997	1870	1438	2431	15533	12952	18629	0.391	0.292	0.522	22734	19410	26627
1998	2837	2246	3584	15148	12668	18113	0.452	0.341	0.599	24196	20888	28029
1999	2939	2323	3719	13144	11013	15687	0.517	0.391	0.684	22580	19577	26045
2000	2872	2272	3631	13141	11124	15524	0.437	0.331	0.579	25131	21891	28850
2001	2459	1931	3131	11627	9913	13638	0.384	0.288	0.512	19554	17026	22457
2002	2436	1919	3091	12451	10649	14557	0.332	0.249	0.442	21536	18756	24727
2003	2772	2206	3483	13519	11519	15865	0.390	0.297	0.513	21971	19101	25271
2004	3086	2462	3868	15101	12828	17776	0.479	0.365	0.628	25448	22164	29220
2005	4049	3182	5151	13244	11247	15595	0.486	0.375	0.629	22337	19485	25607
2006	3833	3033	4846	11762	10021	13806	0.491	0.377	0.639	21336	18638	24426
2007	3616	2875	4547	11941	10229	13939	0.435	0.333	0.569	23562	20604	26945
2008	3874	3072	4885	14288	12263	16647	0.381	0.288	0.504	27599	24102	31604
2009	3873	3045	4924	13745	11785	16030	0.376	0.284	0.498	26473	23096	30343
2010	3239	2562	4095	16170	13807	18938	0.391	0.293	0.522	28970	25198	33306
2011	2183	1721	2769	18554	15780	21815	0.398	0.300	0.529	32022	27751	36952
2012	2462	1937	3128	17640	14963	20797	0.448	0.337	0.596	27754	23990	32110
2013	4557	3581	5799	19061	16126	22530	0.329	0.238	0.456	33037	28577	38195
2014	4664	3648	5962	20065	16849	23895	0.501	0.369	0.681	32716	28222	37926
2015	4324	3266	5724	19820	16680	23551	0.438	0.331	0.581	33727	29059	39144
2016	4567	3382	6167	19364	16363	22916	0.330	0.246	0.441	33003	28257	38548
2017	3770	2637	5392	23319	19623	27711	0.262	0.191	0.360	40377	34048	47882
2018	2353	1519	3647	25740	21307	31095	0.234	0.167	0.328	41814	34476	50714
2019	2124	1209	3732	24360	19632	30227	0.290	0.197	0.428	34812	27949	43361
2020	2424	1165	5045	27531	21094	35933	0.329	0.201	0.540	37741	28751	49543

Table 5.2. Estimated fishing mortality-at-age.

Year /Age	3	4	5	6	7	8	9	10	11	12
1996	0.003	0.014	0.060	0.158	0.304	0.367	0.453	0.546	0.441	0.441
1997	0.002	0.008	0.041	0.127	0.289	0.391	0.517	0.629	0.511	0.511
1998	0.002	0.007	0.033	0.116	0.302	0.449	0.627	0.766	0.629	0.629
1999	0.002	0.008	0.032	0.117	0.334	0.529	0.736	0.871	0.715	0.715
2000	0.001	0.007	0.029	0.104	0.284	0.454	0.636	0.708	0.584	0.584
2001	0.001	0.007	0.026	0.100	0.266	0.389	0.543	0.620	0.490	0.490
2002	0.001	0.008	0.030	0.111	0.273	0.359	0.434	0.483	0.379	0.379
2003	0.001	0.012	0.042	0.147	0.347	0.445	0.499	0.513	0.412	0.412
2004	0.002	0.020	0.064	0.193	0.437	0.545	0.594	0.625	0.495	0.495
2005	0.003	0.022	0.067	0.192	0.421	0.536	0.604	0.674	0.570	0.570
2006	0.003	0.023	0.066	0.183	0.403	0.518	0.610	0.742	0.637	0.637
2007	0.003	0.023	0.067	0.186	0.391	0.462	0.523	0.614	0.516	0.516
2008	0.002	0.016	0.051	0.153	0.331	0.388	0.457	0.576	0.479	0.479
2009	0.001	0.010	0.035	0.121	0.297	0.374	0.475	0.614	0.518	0.518
2010	0.001	0.007	0.027	0.102	0.272	0.392	0.533	0.656	0.573	0.573
2011	0.001	0.008	0.031	0.103	0.260	0.381	0.565	0.683	0.594	0.594
2012	0.001	0.010	0.037	0.115	0.276	0.412	0.657	0.782	0.651	0.651
2013	0.001	0.006	0.026	0.080	0.186	0.292	0.515	0.573	0.508	0.508
2014	0.001	0.011	0.052	0.147	0.306	0.440	0.831	0.782	0.655	0.655
2015	0.001	0.012	0.059	0.149	0.278	0.399	0.684	0.680	0.569	0.569
2016	0.001	0.009	0.051	0.133	0.232	0.326	0.493	0.464	0.406	0.406
2017	0.000	0.005	0.033	0.101	0.198	0.277	0.390	0.345	0.313	0.313
2018	0.000	0.003	0.023	0.082	0.177	0.260	0.350	0.299	0.290	0.290
2019	0.000	0.002	0.019	0.077	0.192	0.331	0.455	0.397	0.395	0.395
2020	0.000	0.002	0.020	0.080	0.204	0.364	0.531	0.467	0.475	0.475

Table 5.3. Estimated stock numbers-at-age.

Year /Age	3	4	5	6	7	8	9	10	11	12
1996	1609	2033	2368	2375	1868	1005	445	183	74	119
1997	1870	1367	1717	1903	1738	1188	602	244	91	107
1998	2837	1621	1185	1372	1422	1119	692	308	113	103
1999	2939	2436	1415	1015	1013	886	615	317	123	100
2000	2872	2486	2091	1238	794	601	443	256	114	94
2001	2459	2500	2118	1716	1002	531	322	198	110	100
2002	2436	2126	2146	1781	1329	675	319	159	90	111
2003	2772	2111	1848	1778	1387	868	407	182	84	119
2004	3086	2388	1849	1541	1291	846	477	212	97	116
2005	4049	2627	2002	1503	1099	715	424	228	97	112
2006	3833	3488	2206	1575	1073	620	362	198	101	103
2007	3616	3292	2902	1781	1119	622	319	171	80	93
2008	3874	3075	2729	2293	1269	657	341	160	81	89
2009	3873	3359	2576	2187	1627	808	392	185	77	91
2010	3239	3384	2835	2155	1636	1008	485	212	86	86
2011	2183	2824	2946	2354	1668	1059	578	247	95	84
2012	2462	1834	2438	2447	1809	1099	626	282	107	84
2013	4557	2043	1506	2053	1904	1160	620	282	110	85
2014	4664	4049	1736	1278	1593	1418	712	326	134	100
2015	4324	3978	3564	1457	962	1011	804	254	129	103
2016	4567	3598	3420	2824	1146	638	582	344	111	111
2017	3770	3982	2948	2764	2089	819	393	311	185	127
2018	2353	3343	3438	2400	2146	1451	532	234	189	196
2019	2124	1991	2903	2933	1944	1470	981	329	153	249
2020	2424	1838	1647	2503	2375	1386	902	533	193	233

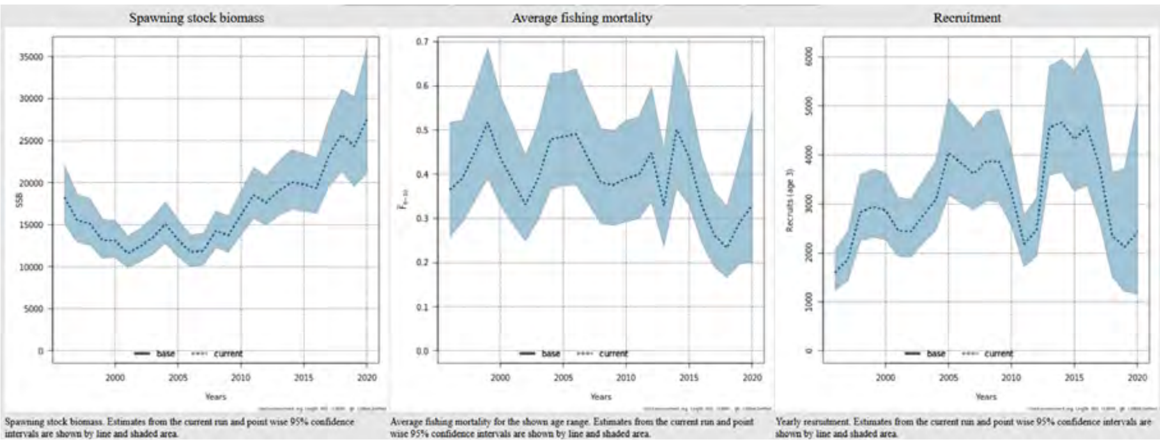


Figure 5.1. Output from SAM; spawning–stock biomass (left), average fishing mortality (ages 6–10) (middle) and recruitment (right).

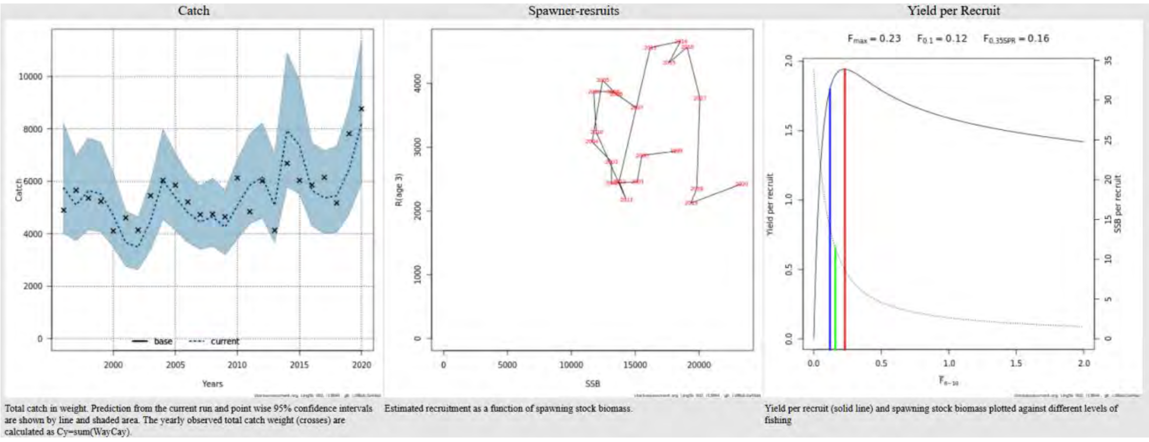


Figure 5.2. Output from SAM; catch per year (left), spawner–recruits plot (middle) and yield per recruit (right).

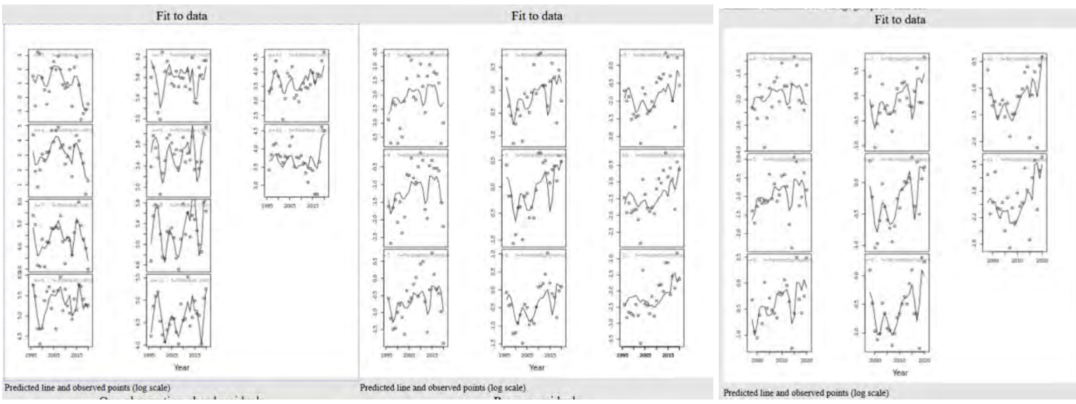


Figure 5.3. Output from SAM; Fit to data-catch (left), summer survey (middle) and spring survey (right).

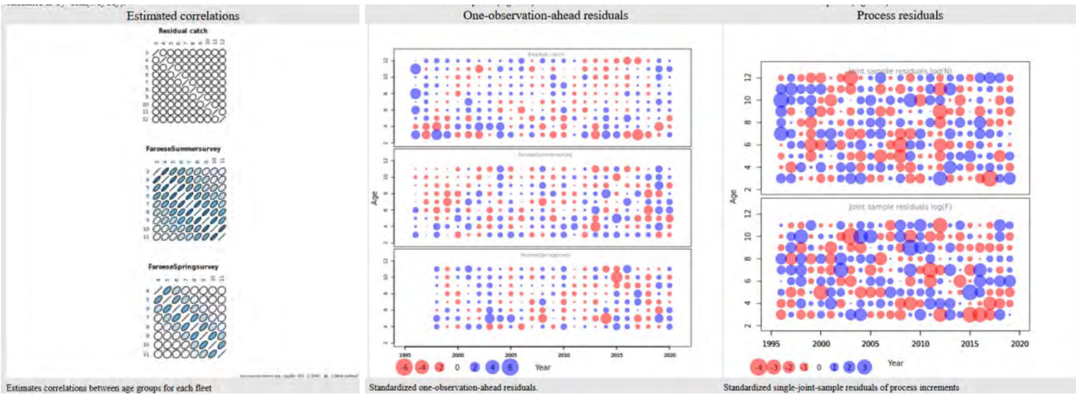


Figure 5.4. Output from SAM; estimated correlations (left), one-observation-ahead residuals (middle) and process residuals (right).

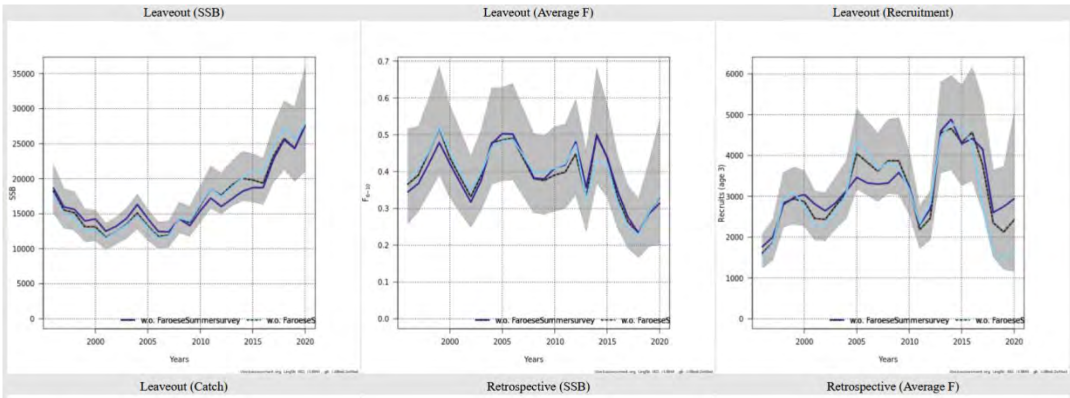


Figure 5.5. Leave-one-out analysis of SSB (left), fishing mortality (middle) and recruitment (right).

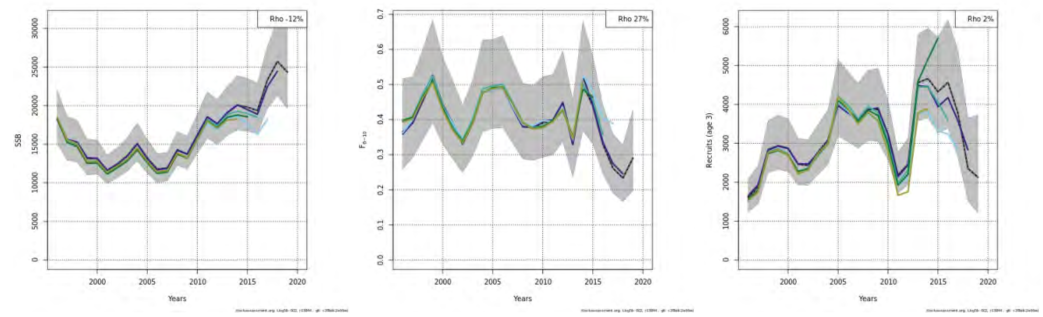


Figure 5.6. Retrospective analysis of SSB (left), fishing mortality (middle) and recruitment (right).

5.3.2 Short-term prediction

The short-term prediction for the stock was performed directly in the final assessment model (SAM). The SAM model provides predictions that carry the signals from the assessment into the short-term forecast. The forecast procedure starts from the last year's (assessment year) estimate of the state (log(N) and log(F) at age). As evident the last assessment year is the year prior to the year when the assessment is done. One thousand replicates of the last state are simulated from its estimated joint distribution. Each of these replicates are then simulated forward according to the assumptions and parameter estimates found by the assessment model.

In the forward simulations a five-year average (years up to the assessment year) is used for catch mean weight, stock mean weight, proportion mature, and natural mortality. Recruitment is resampled from the whole year range (up to the year before the assessment year). In each forward simulation step the fishing mortality is scaled, such that the median of the distribution is matching the requirement in the scenario (e.g. hitting a specific mean F value or a specific catch) (Stock Annex). The results of different forecasts are shown in Table 5.4.

Table 5.4. Forecast when SQ in 2020 and different scenarios such as $F=F_{2020}$, F=0, $F=F_{msy}$, $F=F_{p05}$, $F=F_{lim}$. Median values showed.

	Year	fbar:median	rec:median	ssb:median	catch:median	tsb:median
Rec 25 yr, SQ all years	2020	0.338	2466	27717	8332	38257
	2021	0.338	2939	27970	8475	38013
	2022	0.338	2939	25596	7944	35530
	2023	0.338	2939	22923	7058	33387
Rec 25 yr, SQ then zero	2020	0.338	2466	27717	8332	38257
	2021	0	2939	27970	0	38013
	2022	0	2939	35491	0	45614
	2023	0	2939	42423	0	53370
Rec 25 yr, SQ then F_{msy}	2020	0.338	2466	27717	8332	38257
	2021	0.23	2939	27970	6138	38013
	2022	0.23	2939	28278	6500	38282
	2023	0.23	2939	27481	6286	38047
Rec 25 yr, SQ then F_{p05}	2020	0.338	2466	27717	8332	38257
	2021	0.6	2939	27970	12974	38013
	2022	0.6	2939	20386	9537	30212
	2023	0.6	2939	15615	7001	25930
Rec 25 yr, SQ then F_{lim}	2020	0.338	2466	27717	8332	38257
	2021	0.85	2939	27970	16155	38013
	2022	0.85	2939	16722	9566	26355
	2023	0.85	2939	11539	6268	21777

5.4 Reference points

No reference points have been defined for this stock prior to the WKBARFAR benchmark. In the latest advice (ICES advice, 2019) a $F_{MSY\ proxy}$ of 98.0 cm was used (See stock annex).

At the WKBARFAR benchmark ICES reference point analyses were done following the ICES guidance (ICES, 2017) using the EqSim R-script.

The appropriate data used were the agreed final SAM model input/output. The full time-series of stock and recruitment were used except from the three latest years.

The stock type was identified to Type 6, stocks with a narrow dynamic range of SSB and no evidence that the recruitment is, or has been, impaired (Figure 5.7). No B_{lim} was estimated from these data, only the PA reference points. A segmented regression model for recruitment was used. Recruitment is thought to be strongly auto-correlated for this stock.

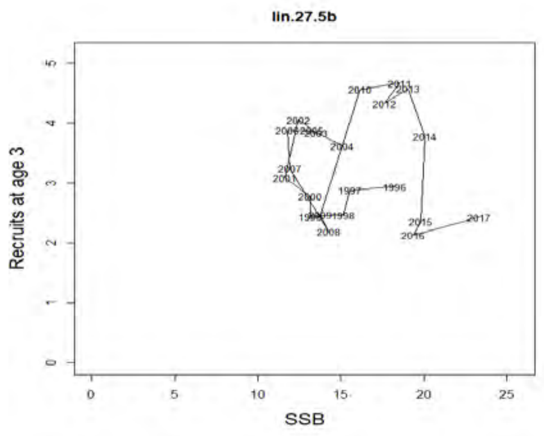


Figure 5.7. Relationship between SSB and Recruits-at-age 3.

Several different settings were explored in EqSim and the results of four of them are presented in Table 5.5. Run nr. 1 to 3 gave very similar results, so nr. 2 was chosen because that was the most precautionary of them. Run nr. 4 was done to check if the setting B_{lim}=B_{loss} changed the F_{MSY} estimate, which it did not. The accepted reference points were obtained from run nr. 2 (Table 5.5, Figures 5.8–5.10) where autocorrelation was applied and B_{pa} = B_{loss} was set to 11 627 t, which is the lowest observed historical SSB (in 2001). B_{lim} was calculated according to the equation: B_{lim} = B_{pa}/exp(sigmaSSB*1.645).

Table 5.5. Different settings and results from the sensitivity runs of EqSim. The results from run nr. 2 (bold) were agreed as reference points.

	Run nr.	1	2	3	4
Settings	stockName	lin.27.5b	**lin.27.5b**	lin.27.5b	lin.27.5b
	runName	Ling5b_002_lho5	**Ling5b_002_lho6**	Ling5b_002_lho7	Ling5b_002_lho_Blim__Bloss
	SAOAssessment	Ling5b_002	**Ling5b_002**	Ling5b_002	Ling5b_002
	sigmaF	0.194025411	**0.194025411**	0.194025411	0.194025411
	sigmaSSB	0.133168647	**0.133168647**	0.133168647	0.133168647
	noSims	1001	**1001**	1001	1001
	SRused	SegregBlim	**SegregBlim**	SegregBlim	SegregBlim
	SRyears_min	1996	**1996**	1996	1996
	SRyears_max	2017	**2017**	2017	2017
	acfRecLag1	0.64	**0.64**	0.64	0.64
	rhoRec	FALSE	**TRUE**	TRUE	TRUE
	numAvgYrsB	5	**5**	10	5
	numAvgYrsS	5	**5**	10	5
	cvF	0.212	**0.212**	0.212	0.212
	phiF	0.423	**0.423**	0.423	0.423
	cvSSB	0	**0**	0	0
	phiSSB	0	**0**	0	0
Results	$MSY_{Btrigger}$	11627	**11627**	11627	14475
	$5thPerc\_SSB_{MSY}$	24310	**21707**	20882	21849
	B_{pa}	11627	**11627**	11627	14475
	B_{lim}	9340	**9340**	9340	11627
	F_{pa}	0.66	**0.62**	0.64	0.47
	F_{lim}	0.9	**0.85**	0.87	0.64
	F_{p05}	0.65	**0.6**	0.62	0.47
	$F_{msy\_unconstr}$	0.23	**0.23**	0.23	0.23
	F_{MSY}	0.23	**0.23**	0.23	0.23

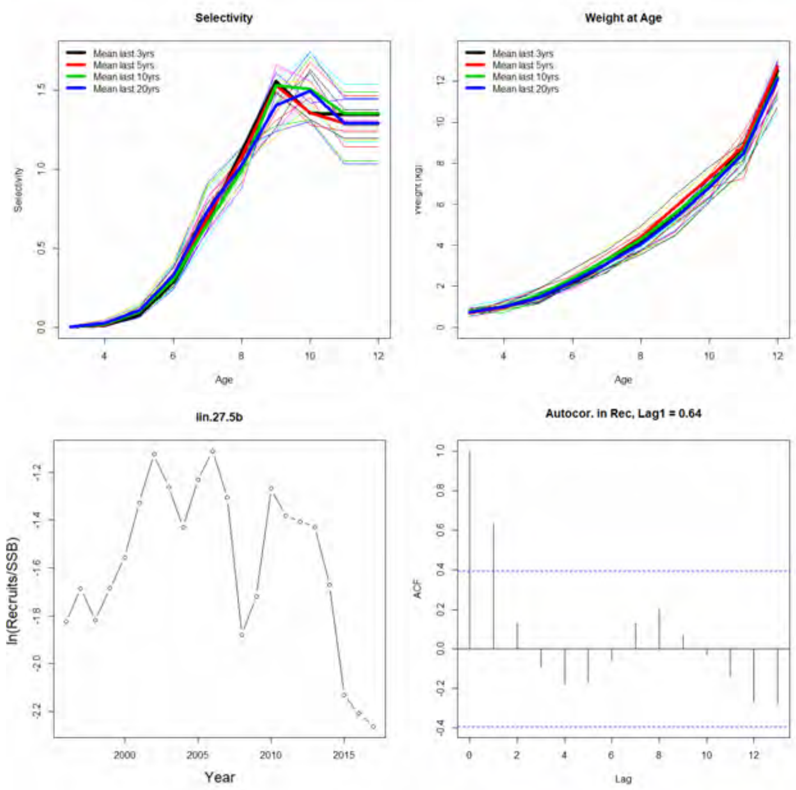


Figure 5.8. Selectivity, weight-at-age, spawning pr recruits and autocorrelation.

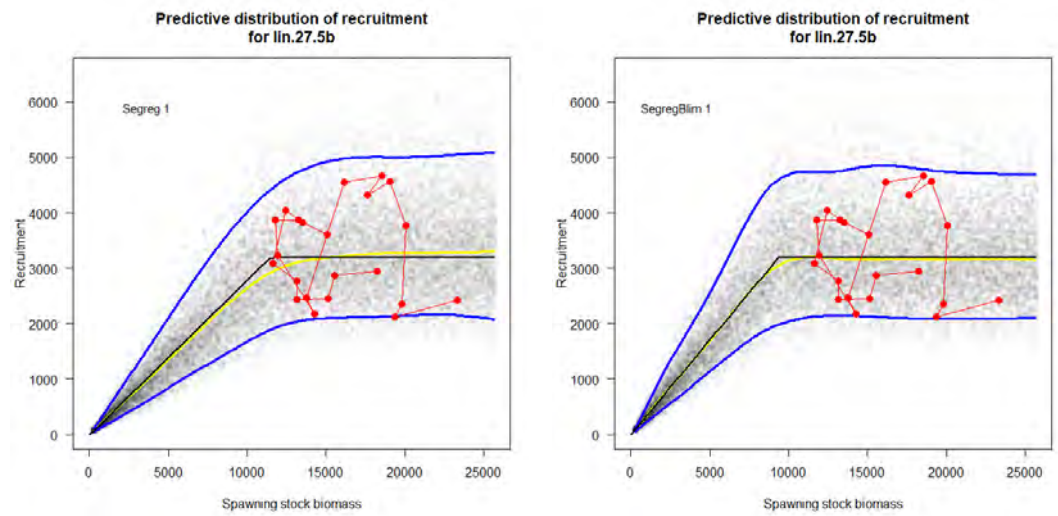


Figure 5.9. Predicted distribution of recruitment.

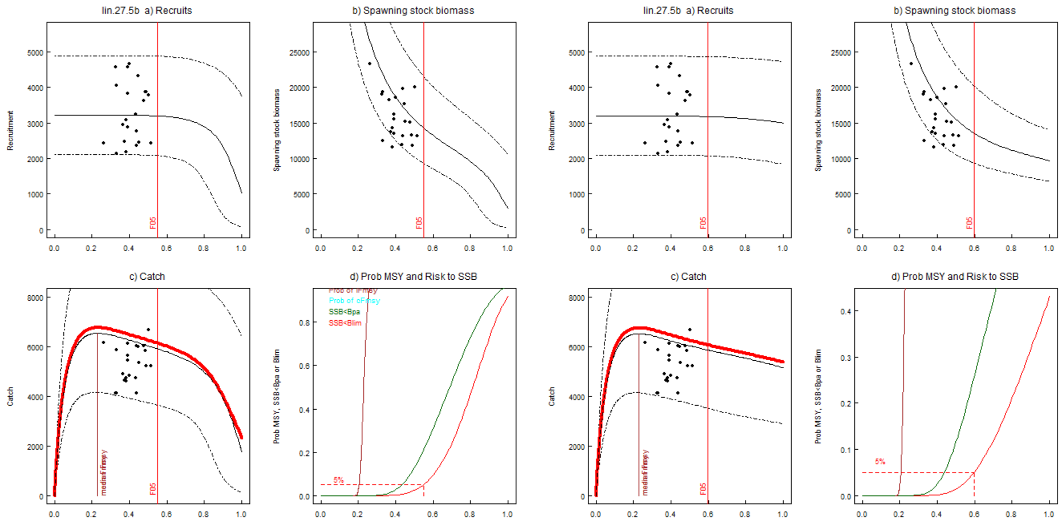


Figure 5.10. Eq MSY plots.

5.5 Future research and data requirements

The aim is to collect enough individual age and maturity samples to cover the Faroese spring- and summer surveys, especially the smallest and largest individuals.

5.6 Reviewer's comments

The reviewers support the adoption of the proposed SAM model as the basis of ICES advice. For full reviewer comments see Section 6.

5.7 References

Eliasen, S.K., Mortensen, E., Steingrund, P., Ofstad, L.H., Homrum, E.í. 2020. An ALK Program to compute age-disaggregated fish based on age-measured and "only-length" measured fish. WD, WKBARFAR 2020. Appendix 2.

ICES. 2017. ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice Technical Guidelines. DOI:10.17895/ices.pub.3036.

Pedersen, M. W., and Berg, C. W. 2017. A stochastic surplus production model in continuous time. Fish and Fisheries, 18: 226–243. doi: 10.1111/faf.12174.

Nielsen A. and Berg C.W. 2014. Estimation of time-varying selectivity in stock assessments using state–space models. https://www.stockassessment.org/docs/selpap-postprint.pdf.

Ofstad, L.H. 2021. Ling in Division 27.5.b. Reviewing the input data to age-based assessment (SAM). WD WKBARFAR DEWK 2021. Appendix 1.

6 Reviewer Report

6.1 General

The reviewers congratulate and thank all the stock assessment staff for the extensive work conducted to prepare for the benchmark meetings, and for the prompt and respectful responses to questions and requests from the reviewers. Given the time differences among participants and not being together in the same room for the many discussions, Daniel Howell provided excellent chairing of the meetings and kept most everything on schedule. Despite having to curtail some discussions, a good job well done.

The benchmark was conducted virtually. Reviewers participated in the following meetings:

1. A single WebEx meeting on November 24, 2020 during which stock experts gave presentations about key data issues and approaches. The purpose of this meeting was to identify issues that required further investigations for the Data Evaluation Workshop.
2. The Data Evaluation Workshop was held 30th November to 4th December.
3. A single WebEx meeting on 25th January, 2021. The purpose of this was to review preliminary runs of the assessment models and to identify issues that stock experts could investigate before the benchmark meeting.
4. WKBARFAR 1st to 5th February 2021.

This multistage approach worked well in terms of making progress on assessment issues. However, the multistage approach does create scheduling issues. Each of these meetings only took 3–4 hours per day. Overall, the virtual format made it feasible for reviewers to participate without travel and associated losses of time.

For the four stocks in question, reviewers were unanimous that the assessments of the Faroe Island Ling, the Northeast Arctic cod (NEA), and the northern coastal cod, and their reference points, were suitable as the basis of advice on these stocks as ICES category 1 assessments. The Precautionary approach and MSY reference points were evaluated in line with ICES guidelines.

For the southern coastal cod, it was unanimous that such advice is premature, other than that the stock appears to be at a low level.

The following is more detailed commentary on each stock:

6.2 Faroes Islands Ling

At the Data Evaluation Workshop, additions of historical landings data as an index, treatment of outliers in survey indices and definition of stock weights were presented as issues to be addressed as inputs to an assessment model. Reviewers agreed that all three of these issues needed to be further evaluation.

At the benchmark an alternative model formulation was presented that in addition to the traditional survey and catch-at-age, included historical landings. Reviewers were unanimous that while this inclusion provided an interesting glimpse into the historical status of the stock, albeit with high uncertainties, it is not feasible as an assessment model. These back projections hinge on the assumption that gear selectivity and interannual deviations in fishing mortality follow the same distribution as in the more data-rich period, which that may not be valid. In addition, the assessment model formulation appeared not to improve the assessment and, based on retrospective analyses, appeared to introduce unwanted estimation issues.

A model diagnostic revealed an issue with the survey data, particularly for the youngest ages in the most recent year. This was attributed to a lack of age samples for juveniles. The proposed solution to borrow from adjacent years appears to have fixed this problem and it was suggested that otolith sampling should be increased. The reviewers note that, even with the proposed increase in sampling from the survey, the numbers of otoliths from some age classes will likely be low as the total number of ling caught in these surveys is fairly low. Hence, borrowing of data may need to be continued, especially for juveniles. This not considered to be a large issue in the short term, as no trends in length-at-age have been observed.

In the short term, reviewers agreed that catch weights would be used as stock weights instead of survey weight-at-age. While it is the general opinion of reviewers that survey weights are preferable over catch weights, only a short time-series of survey weights were available at the benchmark.

The Precautionary approach and MSY reference points were calculated in line with ICES guidelines. B_{pa} was set equal to B_{loss} mainly because the range of estimated SSB values by the stock assessment is relatively narrow, and there is no sign of reduced recruitment when SSB is at the low end of the estimated values. This, in combination with that the fishing pressure appears not to have been overly high, suggests to reviewers that this is an appropriate assumption.

Research recommendations

It is therefore suggested that the use of catch weights as opposed to survey weights-at-age is investigated further, potentially by converting length to weight.

6.3 NEA cod

The November 24 Data Evaluation Workshop identified many issues that required further analysis and review. Revisions to the catch-at-age data were presented. Catch-at-age was expanded to ages 1–12+. The reviewers agreed that this made sense, because catch at these older ages has been increasing. Otherwise, the reviewers were not familiar enough with the catch monitoring systems to recommend alternatives to procedures presented.

Methods used to analyse the winter survey were reviewed. This included revisions to the length-dependent sweep width and how unaged fish are assigned ages in Stox. The reviewers agreed that the new procedures were improvements. An important issue is the northward expansions of NEA cod and also an expansion of the winter survey area in the north. Impacts on assessment model index catchability assumptions were considered. Reviewers agreed to provisionally accept the expanded index, including plus group indices, but wanted to see how it would be fit by the SAM assessment model. The change in survey design in 1994 was also discussed, and it was agreed to consider three options (use 1981–current as a continuous time-series, remove 1981–1993 indices, or split the series into two: 1981–1993/1994–present). The default option is to use the 1981–current as a continuous time-series, and check if there is sufficient evidence to change to another option.

Methods to estimate stock weight-at-age were reviewed, including for plus group. The reviewers agreed that the proposed methods were an improvement, and were the best available information for use at the benchmark meeting.

During the January 2021 pre-benchmark meeting, the revised Joint Barents Sea winter survey was reviewed, including the impact of the survey area expansion. Sequential SAM models were presented to indicate the impacts of changes in the winter survey index, the catch-at-age, change in maturity ogives, and changes in weight-at-age. Change in weight-at-age had little impact, but changes in winter survey indices and catch-at-age had larger impacts. Including the 12+ group rather than individual age estimations resulted in a more realistic assessment model.

At the final benchmark meeting, the assessment team had a base model for the reviewers to consider, but this model had large retrospective patterns. Some of this was related to revisions to the historic catch-at-age data. These revisions of the Norwegian catch data were withdrawn and the reviewers agreed with this was appropriate. However, the assessment team was encouraged to continue the research (see research Recommendation).

The reviewers agreed that the Joint Barents Sea winter survey age 3 index and the 12+ index should be included for fitting SAM. However, model diagnostics also indicated a residual pattern and it was proposed to split the index in SAM at the time the survey area was expanded. The reviewers agreed with this decision.

These changes reduced the retrospective pattern. Several changes in SAM parameter coupling settings were described and reviewers agreed with these. Diagnostics revealed some evidence that the correlation in the SAM F random walk may have changed overtime. As an interim solution, the benchmark decided that an uncorrelated F random walk should be used. This resulted in an improved retrospective pattern but poorer model fit in term of AIC. However, this was the final SAM formulation selected, with a research recommendation to explore ways to account for changes in correlation over time.

Research Recommendations

Continue efforts to improve catch-at-age information. Quantifying uncertainty in catch-at-age (both total catch and age composition) will be helpful when assessing the adequacy of SAM fits to the catch data.

Consider developing a time-series growth model that fits all the available weight-at-age data with the objective of providing the best possible estimates of stock weight-at-age.

The relationship between ice cover and fish distribution is of particular interest with respect to survey coverage and age distribution and warrants investigation.

The estimation of variance in both the large-scale winter survey and the spawning survey need consideration given the autocorrelation of the measures used to estimate means (bootstraps). The spawning survey in particular seems ideal for an expansion of the essentially 1-dimensional approaches being used to 2-dimensional methods that take into account along transect as well as between transect variability.

Reviewers would have liked to see a VPA-style model as a check; this was a casualty of the timing issues with the meetings, so no fault to anyone. If the old XSA model could be updated with plus group indices etc. then it will provide a comparison with the new model. Alternatively, a SAM version specified in VPA style (i.e. no process errors and fit catch-at-age exactly) could be provided, including retrospective runs. The purpose of this diagnostic model is to help reviewers understand how process errors and SAM-inferred errors in catch-at-age affect the assessment.

6.4 Northern coastal cod

At the Data Evaluation Workshop in November, two fundamental stock definition issues were considered. Catch from the NEA cod and coastal cod has been done using differing otolith characteristics. Separation of the coastal fish into north and south stocks, with the split at 67°N was a new proposal. Independent evidence for the split into north and south components came from auxiliary and published genetic analyses and was accepted by reviewers as the basis of assessing the north and south stocks separately.

It was apparent that the data available, given the split, were not comparable so that a full modelled (in this case SAM) assessment was at least possible for the north, but that other "data-poor" methods would be necessary for the south. It was noted that acoustic-trawl surveys have been conducted for both regions, but that more consistent coverage had been obtained for the north, and that a non-directed gillnet CPUE index was also available from a reference index fleet. From the surveys, relative abundance-at-age can be estimated from the acoustic-trawl data or from the trawl data alone. These two series would not be totally independent, but it was agreed that they could provide complementary information on abundance-at-age so both should be tested for use in a SAM model. There was also a suggestion that either could be used as a simpler biomass only index and that this should be tested. Reviewers agreed with the above approaches.

A further issue with the survey was that apparently the data prior to 2003 were thought not be as reliable as those from 2004 on, because of *a priori* information on documented changes in methods and participants in the surveys. In addition, the substantial recreation catch was uncertain with no local estimates of the mortality rates of fish not kept.

At the pre-benchmark meeting, most all of the above suggestions and issues were explored and addressed. Of particular importance, the acoustic-trawl abundance-at-age data appeared to be most consistent of the various survey combinations tested, but a change in the "q" of the survey was likely after 2004. Reviewers supported testing both the full series and two independent series split pre- and post-2004.

At the benchmark meeting, the acoustic-trawl survey abundance-at-age data were presented as most likely to provide suitable input to the model. The split of the data pre- and post-2004 was also presented, as were using the Lorenzen size-based M estimates (and others) rather than a constant. Reviewers agreed that the split acoustic-trawl survey index and Lorenzen M estimates were most suitable as model inputs.

The suggestion to include spent fish in estimations of the maturity ogive was supported by reviewers, as the numbers of spawning fish encountered during the surveys were very low. On a related issue, important for management advice, was that the SSB–R relationship from the accepted model appeared near linear (two production periods perhaps) with little evidence that the relationship had reached an asymptote during the period of measure. Reviewers agreed that the upper SSB measured to date was the most appropriate reference point for limit biomass. Based on this the stock appears to be subject to recruitment overfishing and likely has not reached its sustainable production potential.

Research Recommendations

Recreational catches should be better measured, especially with evidence that they are a substantial component of the F (25%?) and possibly growing. Better estimation of discarding mortality in these fisheries is also recommended, as the 20% based on research in other regions may not apply, and with some fisheries, such as those practiced with gillnets in deeper waters, may grossly underestimate the actual mortality rate.

6.5 Southern coastal cod

This stock is in the "data-poor" category but some of that may reflect the difficulty of developing reliable indices of abundance for stocks at low states, or perhaps with much lower production potential than the northern coastal stock, or both.

The difficulty of assessing this stock is recognized, as are the attempts that were made to make sense of the available data by the scientists involved.

At the Data Evaluation Workshop, it was presented that the same type of data was available as for the Northern coastal stock, but survey coverage, both acoustic transects and fishing sets, was much less consistent and resultant abundance-at-age data were much more inconsistent from year to year than in the northern region. Consistent patterns in the year-to-year abundance-at-age estimations were difficult to discern. In contrast, the CPUE data from the reference fleet appeared to be declining over recent years. Two methods to address the stock were proposed, the first a length-based spawning potential ratio (LBSPR) method, which none of the reviewers had experience with, and a more traditional biomass model based on catch and abundance indices.

For the LBSPR method, adjusting the length data from the reference fleet was supported by reviewers, as these data were obviously biased. In addition, removing some data from the acoustic record that were too high to be realistic for cod and likely resulted from bottom integration, was supported.

The biomass model had several issues, perhaps critical in terms of using this model at present. The major problem was that the two indices considered, the acoustic-trawl and reference fleet CPUE, showed very different trends. A request was made that survey coverage be discussed in more detail.

A presentation at the benchmark meeting describing the survey coverage and trawl backup in more detail indicated there were several years when coverage was inadequate. Overall, however, the coverage was not as poor as thought at the Data Evaluation Workshop. Nonetheless, using the censored acoustic data, the disparity between the survey index and the reference fleet CPUE remained, and presenters seemed to "trust" the CPUE index more, hence the survey index was discarded. It was not entirely clear that this was justified. A run of the model with only the survey index was not presented.

The LBSPR became somewhat clearer at the benchmark meeting, but still confusing as to how this would inform management.

Research recommendations

For future reviews of a developing LBSPR model, it is recommended that at least one reviewer have specific expertise with this method.

As a comment, it is puzzling that the acoustic-trawl survey seems to be reasonably reliable for the Northern coastal stock but not for the Southern coastal cod. There may be good reasons for this, but it was not entirely clear what they were. Favouring CPUE fleet data over survey data has led some stocks down the garden path (e.g. Northern cod). This bears further scrutiny; there is no doubt that when stocks are very low, as appears here, it becomes increasingly difficult to get detailed age-structured data.

Annex 1: List of participants

Name	Address	Country	E-mail
Asgeir Aglen Stock Coordinator	Institute of Marine Research	Norway	Asgeir.aglen@hi.no
Erik Berg	Institute of Marine Research Tromsø	Norway	erik.berg@hi.no
Matthias Bernreuther	Thünen Institute	Germany	Matthias.Bernreuther@thuenen.de
Bjarte Bogstad Stock Assessor	Institute of Marine Research	Norway	Bjarte.bogstad@hi.no
Olav Nikolai Breivik	Norwegian Computing Centre	Norway	Olav.Nikolai.Breivik@nr.no
Noel Cadigan Invited Expert	Marine Institute Memorial University of Newfoundland	Canada	Noel.Cadigan@mi.mun.ca
Anatoly Chetyrkin	Polar Branch of Russian Research Institute of Marine Fisheries and Oceanography	Russia	chaa@pinro.ru
Gjert Endre Dingsør	Norwegian Fishermen’s Association	Norway	gjert@fiskebat.no
Elise Eidset	Institute of Marine Research Bergen	Norway	elise.eidset@hi.no
Bjarki Thor Elvarsson Invited Expert	Marine and Freshwater Research Institute	Iceland	bjarki.elvarsson@hafogvatn.is
Johanna Fall	Institute of Marine Research Bergen	Norway	johanna.fall@hi.no
Edvin Fuglebakk	Institute of Marine Research	Norway	Edvin.fuglebakk@hi.no
Harald Gjøsæter	Institute of Marine Research Bergen	Norway	Harald.Gjoesaeter@hi.no
Daniel Howell Chair	Institute of Marine Research Bergen	Norway	Daniel.howell@hi.no
Torild Johansen	Institute of Marine Research Bergen	Norway	Torild.johansen@hi.no
Knut Korsbrekke	Institute of Marine Research Bergen	Norway	knut.korsbrekke@hi.no
Yuri Kovalev Stock Coordinator	Polar Branch of Russian Research Institute of Marine Fisheries and Oceanography-PINRO	Russia	kovalev@pinro.ru
Anders Nielsen	DTU Aqua	Denmark	an@aqua.dtu.dk
Kjell Nedreaas	Institute of Marine Research Bergen	Norway	kjell.nedreaas@hi.no

Name	Address	Country	E-mail
Lise Ofstad Stock Coordinator	Institute of Marine Research	Faroe Islands	liseo@hav.fo
Kotaro Ono	Institute of Marine Research Bergen	Norway	Kotaro.Ono@hi.no
Alfonso Perez Rodriguez	Institute of Marine Research Bergen	Norway	alfonso.perez.rodriguez@hi.no
Yves Reecht	Institute of Marine Research	Norway	yves.reecht@hi.no
George Rose Invited Expert	Institute for the Oceans and Fisheries University of British Columbia	Canada	g.rose@oceans.ubc.ca
Alexey Russkikh	Polar Branch of Russian Research Institute of Marine Fisheries and Oceanography-PINRO	Russia	russkikh@pinro.ru
Silje Seim	Institute of Marine Research Bergen	Norway	silje.elisabeth.seim@hi.no
Petur Steingrund	Institute of Marine Research	Faroe Islands	peturs@hav.fo
John Tyler Trochta	Institute of Marine Research	Norway	j.t.trochta@gmail.com
Dmitri Vasilyev	Russian Federal Research Institute of Fisheries and Oceanography	Russia	dvasilyev@vniro.ru
Natalia Yaragina	Polar Branch of Russian Research Institute of Marine Fisheries and Oceanography-PINRO	Russia	yaragina@pinro.ru

Annex 2: Stock Annexes

The table below provides an overview of the Stock Annexes updated by WKBarFar 2021. Stock Annexes for other stocks are available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular Stock Annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species,* and *acronym* of the relevant ICES expert group.

Stock ID	Stock name	Last updated	Link
cod.27.1–2	Cod (*Gadus morhua*) in subareas 1 and 2 (Northeast Arctic)	March 2021	NEA cod
Coastal cod south	Norwegian coastal cod (*Gadus morhua*) between 62 and 67°N	April 2021 **DRAFT**	Coastal cod south
Coastal cod north	Norwegian coastal cod (*Gadus morhua*) north of 67°N	March 2021 **DRAFT**	Coastal cod north
lin.27.5b	Ling (*Molva molva*) in Division 5.b (Faroese grounds)	April 2021	Ling in 5.b

Annex 3: Working documents

The working documents listed below were made available to the WKBARFAR 2021. A number of these are inserted in this annex in full below this list.

WD 1: Revision of NEA cod tuning indices from the Barents Sea Norwegian-Russian Winter Survey. Johanna Fall.

WD 2: Appendix 1: Ling in Division 27.5.b. Reviewing the input data to the age-based assessment (SAM). Lise H. Ofstad.

WD 3: Appendix 2: An ALK program to compute age-disaggregated fish based on age-measured and "only-length" measured fish. Sólva Eliassen, Ebba Mortensen, Petur Steingrund, Lise H. Ofstad and Eydna í Homrum.

WD 6: Revision of NEA cod catch data. Bjarte Bogstad and Kjell Nedreaas.

WD 7: Revised Norwegian catch data and catch-at-age for cod (*Gadus morhua*) in ICES Subareas 1 and 2 during 1994–2019 due to revised conversion factors. Åge Fotland and Kjell Nedreaas.

WD 11: Scheme for estimating data on the Russian catches of Northeast Arctic cod. N.A. Yaragina, Yu.A. Kovalev, A.A. Russkikh.

WD 12: Northeast Arctic cod mean weight at age in stock. Problems and proposals. Y.A. Kovalev and N.A. Yaragina.

WD 13: Data series on recreational and tourist fisheries for Norwegian Coastal Cod. Kjell Nedreaas, Keno Ferter, Jon Helge Vølstad, Håkon Otterå and Asgeir Aglen.

WD 14: New abundance index series for Norwegian Coastal Cod north of 62°N. Asgeir Aglen, Johanna Fall, Harald Gjøsæter, Arved Staby.

WD 16: Status of the coastal cod (*Gadus morhua*) between 62°N and 67°N using a Length-Based Spawning Potential Ratio (LBSPR) approach. Yves Reecht, Kotaro Ono, Sofie Gundersen and Kjell Nedreaas.

WD 17: Estimating the status of coastal cod (*Gadus morhua*) north of 62°N (ICES Subarea 2) using CPUE data from the Norwegian coastal reference fleet. Kotaro Ono, Sofie Gundersen, Yves Reecht and Kjell Nedreaas.

WD 18: Data and methods for calculation of Norwegian coastal cod natural mortality. Johanna Fall.

WD 19: An ALK program to compute age-disaggregated fish based on age-measured and "only-length" measured fish. Sólva Eliassen, Ebba Mortensen, Petur Steingrund, Lise H. Ofstad and Eydna í Homrum.

WD 20: Calculation of catch at age of ling in Faroese waters using the Faroese ALK-program. Lise H. Ofstad.

WD 21: Background data and growth of ling in Faroese waters (Division 5.b). Lise H. Ofstad.

WD 22: Maturity of ling in Faroese waters (Division5.b). Lise H. Ofstad.

WD 23: Calculation of tuning series of ling from surveys in Faroese waters using the Faroese ALK-program. Lise H. Ofstad.

WD 24: Commercial Abundance Index of ling from Faroese longliners and trawlers 1996–2019. Lise H. Ofstad.

WD 25: Comparison of different methods for prediction of NEA cod mean weight at age in stock. Y.A. Kovalev.

WD 26: A state–space assessment model for Norwegian coastal cod north of 67°N. Johanna Fall.

WD 27: Exploring new approaches to define stock weight at age in the NEA cod short term forecast. A. Perez-Rodriguez.

WD 28: Exploring new approaches to define weight at age in the commercial catches in the NEA cod short term forecast. A. Perez-Rodriguez.

WD 29: Exploring new approaches to define fishing selectivity at age in the commercial catches in the NEA cod short term forecast. A. Perez-Rodriguez.

WD 30: Exploring new approaches to define maturity at age in the NEA cod short term forecast. A. Perez-Rodriguez.

WD 31: An update of the long-term simulations for Northeast Arctic cod. Yury Kovalev.

WD 32: NEA cod stock assessment by means of TISVPA. D. Vasilyev

WD 33: Coastal Cod South Annual Survey Coverage. Harald Gjøsæter.

WD XX: Estimating variance for a trawl acoustic survey targeting spawning NEA cod. Knut Korsbrekke.

WD xx: Coastal cod Shallow water surveys south of 68 degN. Asgeir Aglen.

WD-19_ Coastal cod Shallow water surveys south of 68 degN

Along the coast in Statistical areas 6 and 7 (Møre, Trøndelag and Nordland) there are large shallow water areas, that seem important for juvenile coastal cod. These areas are too shallow to be covered by the large research vessels used in the late autumn survey.

Based on experience from fyke-net and trammel net surveys further north (Sundby at al 2013) some new surveys, with a 50 feet vessel operating gill nets, and a 17 feet vessel operating fyke nets, have been worked in shallow waters:

-From Vikna (65 gr N) to Steigen (68 gr N) in August 2013, 2016 2018, and 2020,

-And in shallow waters from Stad (62 gr N) and Vikna (65 gr N) in August 2015, 2017 og 2019.

The number of gears used per day were 6 double fyke-nets (Figure 1) and 2 trammel net settings, each setting including two nets of 36mm (bar) and two nets of 45mm (bar).

Figure 1. <u>Double «eel» fyke net</u>: From left; 1 fish chamber and 3 trunks, then guiding net, then 3 trunks and fish chamber. The second half mirrors the first. In total there are 4 fish chambers. (from van der Meeren, 2018)

It was decided to use 6 double fyke nets (Figure 1) and 2 gill net sets per fishing day.

For the fyke nets typical fishing depth was between 3m and 12m, and typical soak time 22 hours. For the gill nets typical fishing depth was between 10 m and 25m and typical soak time 12 hours.

Between Vikna (65 degN) and Steigen (68 degN) and in August 2013, 2016 2018 and 2020

Within the Vikna- Steigen area 49 candidate fishing areas were defined, each suitable for one day fishing (Figure 2). Among those areas, 12 were fished in 2013, 21 in 2016 and 20 in 2018. Among those 20 fished in 2018; 11 have been fished in all 3 years, 8 in 2 years and 4 has been fished only one year. R/V "Fangst" was used in all surveys. Figure 3 shows the locations for the individual gears in the fishing area Mudvær.

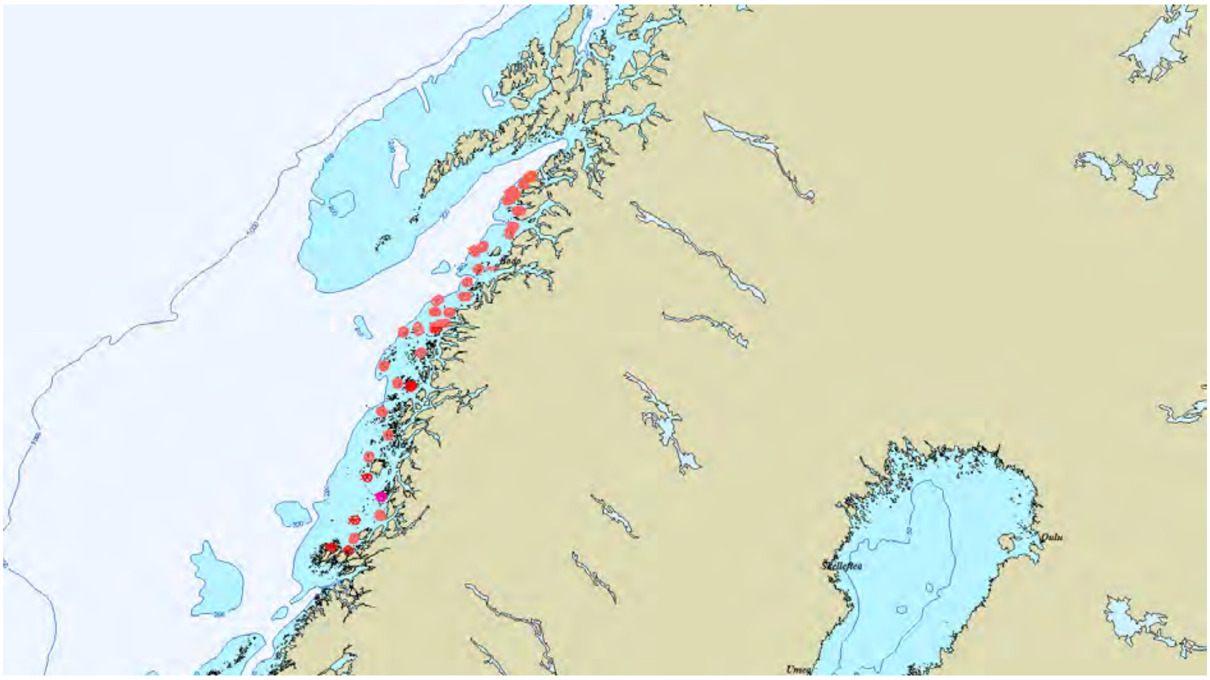


Figure 2. Predefined fishing areas Steigen-Vikna. (Scaling Max Sea; 1:1.5 mill).

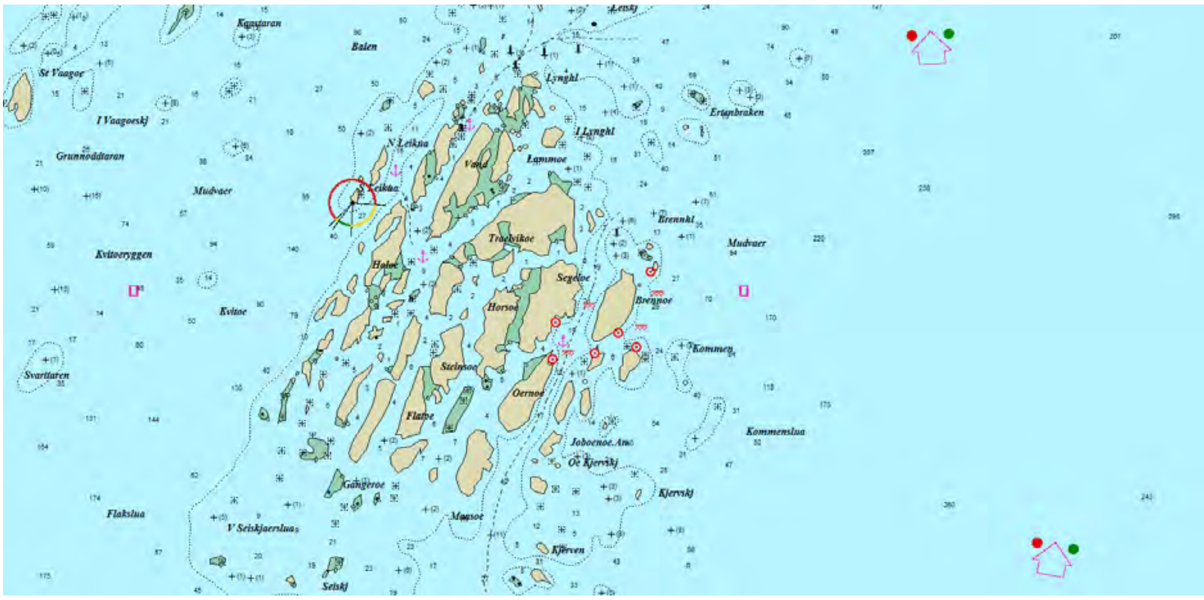


Figure 3. Mudvær, Vega; Example of gear positions within a selected fishing area. Red circles are fyke net positions, and xxx are start point and end point for trammel nets. (Scaling Max Sea; 1:25000).

Results cod, Vikna (65 degN) - Steigen (68degN)

Tabell 1. Average number of cod pr fishing day, Vikna- Steigen

yr	# fishing-days	# cod Pr day	CV of the mean %
2013	12	**42.8**	**17**
2016	21	**41.6**	**14**
2018	20	**47.5**	**12**
2020	24.5	**32.4**	**na**

Table 2. Average number of cod pr fishing day and ages

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9+**	**Total**
2013	2.8	16.4	10.8	6.6	3.5	1.3	0.9	0.2	0.2	0.2	42.8
2016	2.9	11.3	12.0	7.0	5.6	1.0	1.2	0.4	0.3	0.1	41.6
2018	6.8	13.2	13.7	5.6	3.4	1.8	2.2	0.3	0.2	0.3	47.5
2020*	2.4	13.4	8.2	5.0	2.7	0.4	0.3	0.1	0.0	0.0	32.4

In all the 4 years ages 1, 2 og 3 were more abundant than older ages (Table 1). For most ages the 2020 results are lower than previous years. The CVs indicates that small changes between years are not significant. *(age readings 2020 not completed. 2020 numbers at age based on the 2018 age/length key).

Shallow water surveys between Stad (62 degN) and Vikna (65 degN) in August 2015, 2017 and 2019

In the Stad- Vikna - area 46 fishing locations were defined. (Figur 14). Among those, 23 were fished in 2015, 21 i 2017 og 22 in 2019. Among the 22 fished in 2019; 20 had been fished either in 2015 or in 2017. Two of the locations in 2019 (Ona and Nordøyan) have not been fished in earlier years. R/V "Fangst" was used in all surveys. As for the Steigen-Vikna region the criteria for choosing fishing area was to have a fair coverage of the whole region, with some adjustments to take account of bad weather (and to avoid too long travel between locations). Figure 5 shows an example of gear positions within a selected fishing area (Dyrøysvaet, Smøla).

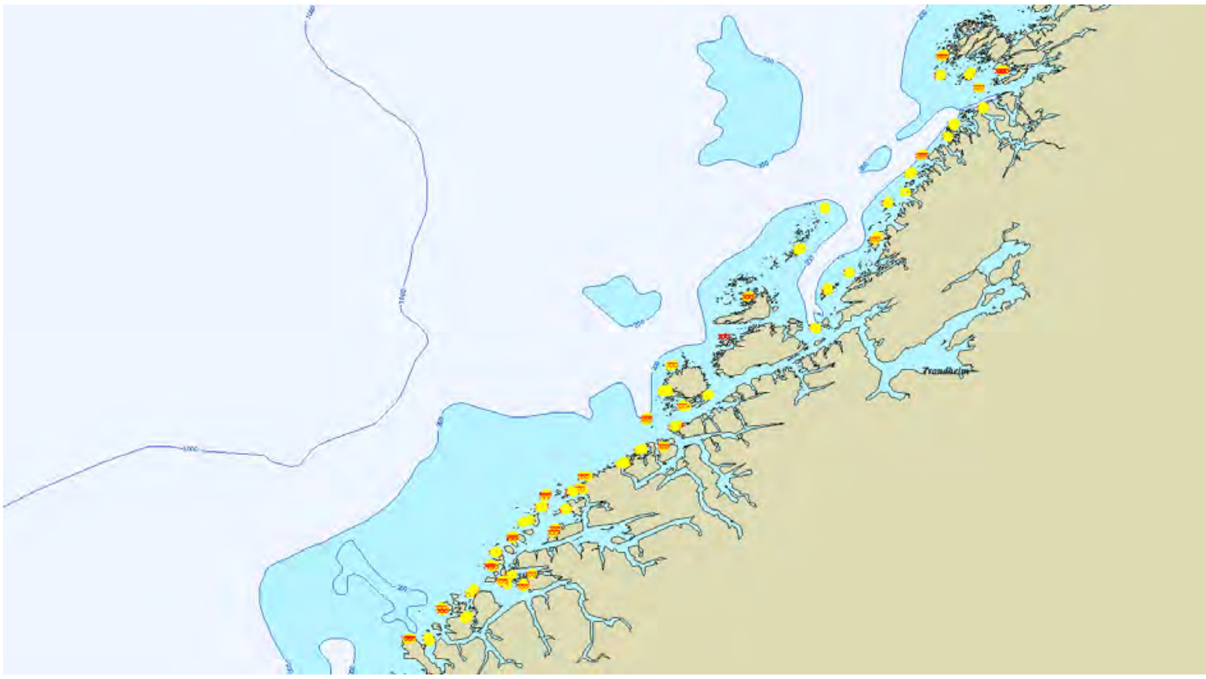
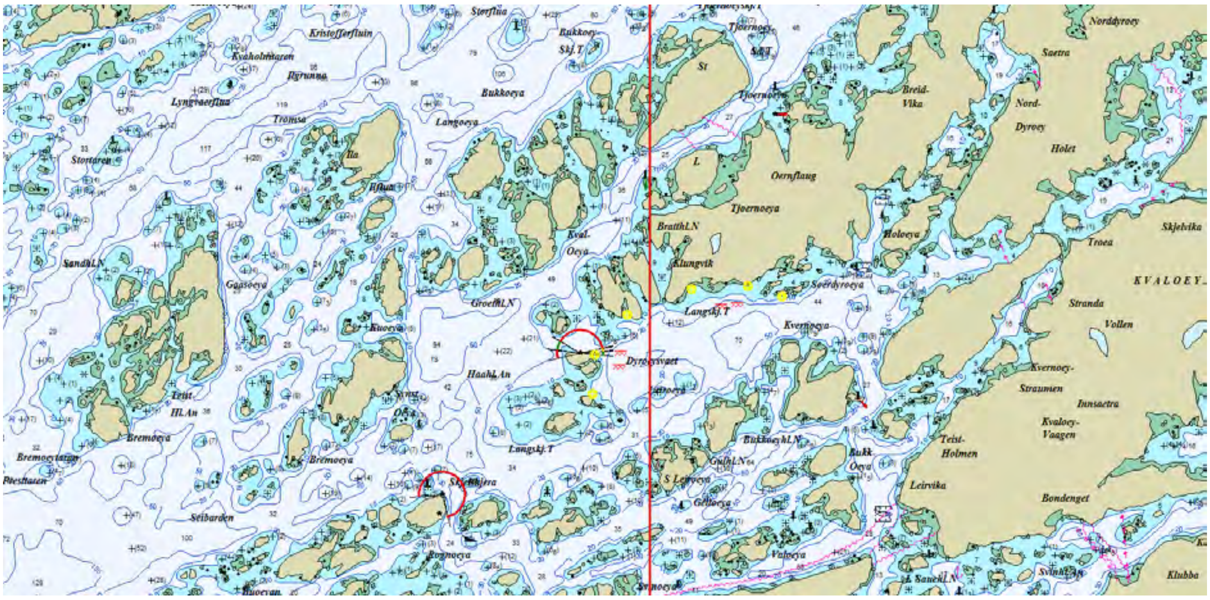


Figure 4. Forhånds-definerte fiskelokaliteter Vikna-Stad. (Skala Max Sea; 1:1.5 mill).



Figur 5. Dyrøysvaet, Smøla; Example of gear positions within a selected fishing area. Yellow circles are fyke net positions, and xxx are start point and end point for trammel nets. (Scaling Max Sea; 1:25000).

Results cod, Stad- Vikna

Tabell 3. Average number of cod pr day, Stad- Vikna

År	# fishing-day	Av# cod Pr day	CV of the mean %
2015	23	**19.6**	**13**
2017	21	**22.1**	**11**
2019	22	**18.6**	**16**

Tabell 4. Average number of cod pr day by age, Stad-Vikna

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9+**	**Total**
2015	0.10	6.57	5.76	3.34	1.31	1.31	0.71	0.20	0.20	0.00	19.6
2017	3.52	9.92	3.85	1.90	1.20	0.86	0.41	0.19	0.14	0.05	22.1
2019	1.09	9.28	4.12	2.31	0.77	0.76	0.08	0.09	0.09	0.00	18.6

Catch rates for cod in this region (Tabell 3 og 4) were in general lower compared to the Vikna-Steigen area (Tabell 1 og 2). In all three years the most abundant ages were 1, 2 og 3.

Total number of cod per day in 2019 (Table 1) are similar to previous years. For ages 4 to 9+ the 2019 results appear reduced compared to the 2015 and 2017 results (Table 4). The CVs indicates that small changes between years are not significant.

Ling in Division 27.5.b. Reviewing the input data to the age based assessment (SAM).

Lise H. Ofstad (liseo@hav.fo)

Introduction

Several decisions were made on the basis of the presentations of ling at the WKBARFAR DEWK net meeting in December 2020. Here, a summary of the data presentations, WDs and decisions made at DEWK is presented.

Spatial distribution

The two scientific Faroe Plateau groundfish surveys cover the main distribution area and fishing area of ling in Faroese waters (Figures 1-2).

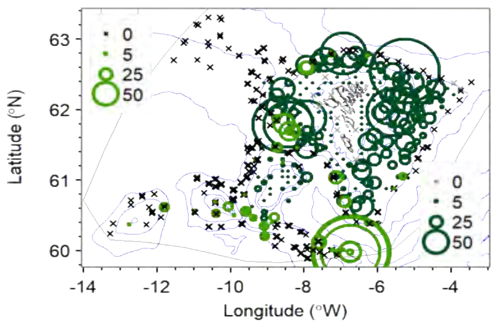


Figure 1. Spatial distribution of ling in the Faroese summer survey (dark green, mean cpue 1996-2017) and in the deepwater survey (green, cpue 2014-2019).

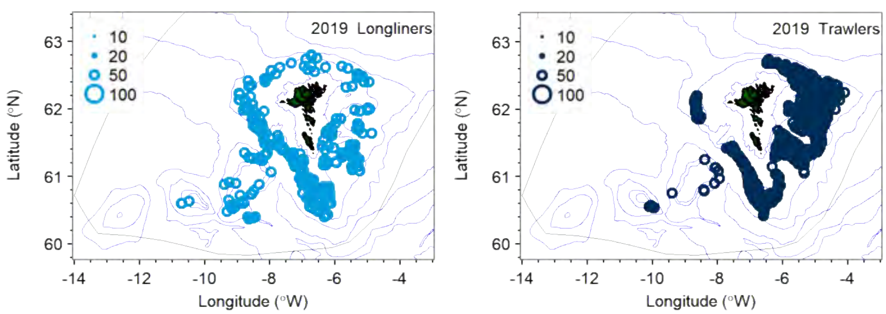


Figure 2. Spatial distribution of ling in 2019 based on the Faroese longliners (left) and Faroese trawlers (right, here used as a bycatch series).

Data

The Faroese data on ling is derived from scientific samplings of landings (catches, length, weight and age (Table 1)), logbooks from commercial trawlers (abundance index) and information from surveys (lengths, weights, age, maturity (Table 2) and abundance index). There are two annual Faroese groundfish surveys on the Faroe Plateau (see stock annex). These surveys are especially designed for cod, haddock and saithe. All these data are stored in databases at the Faroese Marine Research Institute (FAMRI). The background data is a bit patchy some years, so assumptions for the data poor years need to be done in the calculations.

Table 1. Overview of the sampling from commercial landings (number of measurements).

	Length			**Gutted weight**			**Age**		
	Longliners	**Trawlers**	**Other**	**Longliners**	**Trawlers**	**Other**	**Longliners**	**Trawlers**	**Other**
1994	1940	832	785	0	0	0	0	0	0
1995	2385	351	713	0	0	0	0	0	0
1996	5003	1426	48	290	120	0	709	375	0
1997	6493	1407	0	361	180	0	1195	331	0
1998	4163	1651	193	180	358	0	723	358	0
1999	3024	1067	445	180	120	60	240	180	60
2000	1719	1793	0	120	240	0	120	240	0
2001	2243	1562	0	180	240	0	180	240	0
2002	1845	2454	0	60	120	0	120	180	0

2003	4533	2052	0	120	240	0	421	240	0
2004	4350	2477	0	990	179	0	480	179	0
2005	4995	2172	0	3097	120	0	420	120	0
2006	4936	1291	0	3576	1082	0	157	119	0
2007	2077	1662	172	1034	447	172	60	60	0
2008	1432	1087	0	1215	730	0	60	0	0
2009	2127	2246	0	2102	2246	0	112	120	0
2010	1421	2502	422	1421	2436	422	60	120	0
2011	1438	1765	202	1438	1188	202	0	0	0
2012	1413	1397	0	1283	1164	0	50	0	0
2013	1040	1437	0	1040	1036	0	0	0	0
2014	827	1953	205	827	1242	205	0	20	0
2015	820	1724	0	820	1351	0	40	170	0
2016	1432	1329	0	1432	928	0	180	180	0
2017	1201	1776	0	1201	1225	0	239	241	0
2018	2717	4726	0	2717	4726	0	659	1013	0
2019	2890	3576	0	2890	3576	0	300	592	0
2020	1276	2698	0	705	1911	0	360	569	60

Table 2. Overview of the sampling from surveys (number of measurements).

	Length			**Round weight**			**Age**			**Gender and maturity**		
	Spring	**Summer**	**Other**	**Spring**	**Summer**	**Other**	**Spring**	**Summer**	**Other**	**Spring**	**Summer**	**Other**
1994	174		99	10		34	0		20	0		29
1995	273		587	0		76	0		23	0		61
1996	398	1013	235	129	216	26	0	0	11	0	0	15
1997	460	631	274	0	247	79	0	0	0	0	0	0
1998	514	648	280	190	462	173	0	0	0	230*	20	5
1999	300	372	84	252	355	62	0	0	0	248*	3	7
2000	245	433	498	244	360	313	0	0	0	14	1	0
2001	347	553	600	265	503	472	0	0	0	28	0	2
2002	285	510	542	222	477	389	0	0	0	0	0	0
2003	389	284	660	345	284	582	0	0	0	0	0	0
2004	284	857	418	284	802	345	0	0	0	0	0	0
2005	321	821	172	264	719	161	0	0	0	0	0	0
2006	271	647	220	264	612	214	0	0	0	0	1	0
2007	268	729	99	247	662	99	0	0	0	0	0	0
2008	309	973	66	208	779	65	0	0	0	0	10	0
2009	413	859	152	371	608	152	0	0	0	0	0	0
2010	395	1637	125	281	1021	125	0	0	0	0	0	0
2011	507	1826	167	411	1400	165	0	0	0	3	0	0
2012	518	1160	145	518	1109	144	0	0	0	0	0	0
2013	427	1232	120	427	1105	120	100	78	96	100	78	114
2014	336	1725	674	330	1280	658	161	195	200	177	195	206
2015	562	1440	1077	496	1043	962	92	92	234	100	91	235
2016	409	1366	550	409	1265	550	131	191	110	131	193	110
2017	372	1004	306	308	914	247	124	201	112	126	203	115
2018	265	712	682	265	687	682	228	221	343	227	222	345
2019	490	1318	465	435	1089	465	144	147	155	144	147	162
2020	665	900	249	594	884	249	181	140	99	186	140	99

Growth

At the Faroe Marine Research Institute the same age reading method for ling has been used all years since 1996. The mean length at age was investigated back in time and there were no abnormality found. A comparison of mean length at age 2 to 19 from surveys in Iceland and Faroes were compared and results showed that up to age 16 the Icelandic age-length matched up really well to the Faroese ones (Figure 3). A small scale otolith exchange showed that mean CV on ling was 10.3% by 9 age readers (WKAMDEEP 2013), which is low enough to support age-structured analytical assessments for ling.

The WKBARFAR agreed that the ageing of ling was adequate.

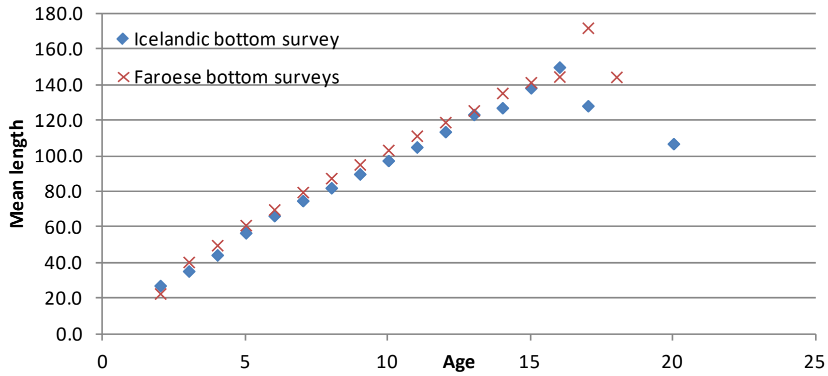


Figure 3. Comparison between Icelandic and Faroese ageing of ling.

Assumptions in ALK-calculations

Calculation of catch number at age and catch/stock weight at age was done by using an ALK program made at the Faroe Marine Research Institute (Ling Annex 2). The same ALK-program is also used for Faroe Plateau cod, Faroe haddock and Faroe saithe.

In the ALK calculations all the age read data were pooled over years, seasons (Jan-Apr, May-Aug and Sep-Dec) and source (surveys, longlines and trawlers). The main reason for the pooling was low numbers of age readings. A closer look at the data for all years pooled, split into season and fleet, showed very little variation between the sources and fleets (Figure 4). The variation between years and between season and source is probably less than the variation in length measurements and age reading, so the data will to be more robust when all data are pooled. In addition, in the Faroese ALK program, the ages were distributed on 5 cm length bins to make it more robust.

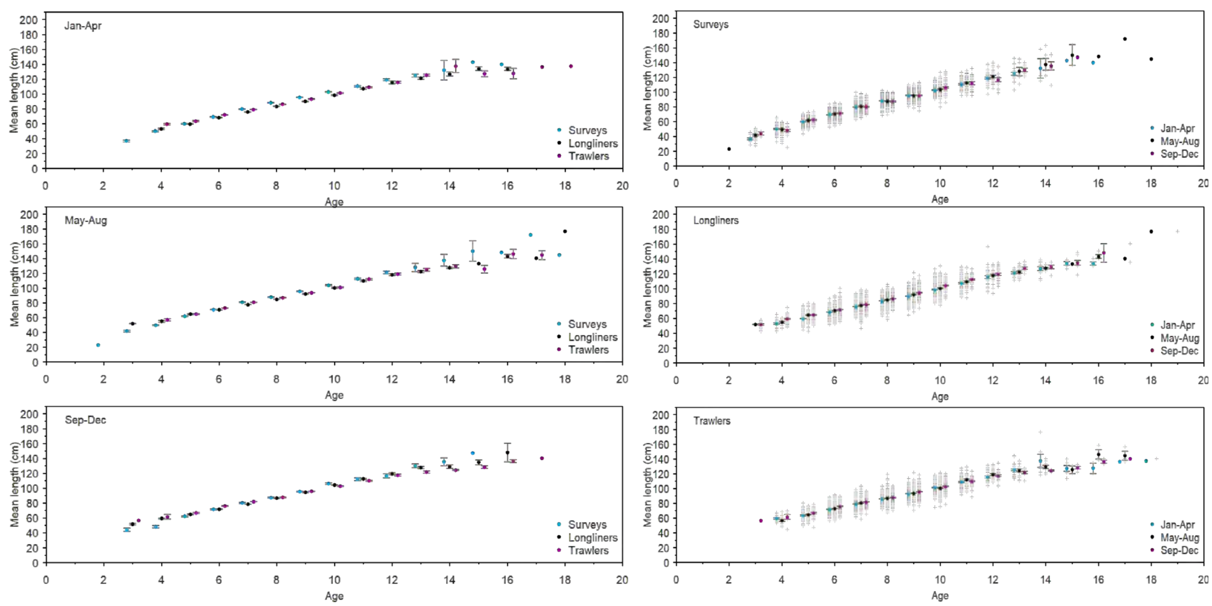


Figure 4. Mean length at age for surveys, longliners and trawlers for January-April, May-August and September-December for all years pooled (left) and mean length at age for January-April, May-August and September-December from surveys, longliners and trawlers for all years pooled (right).

Catch numbers at age

Catch-at-age data are provided for the Faroese landings. There are regular length measurements from longliners and trawlers available from 1996 and some measurements of gutted weights and ages (Table 1). There is, however, a need to improve the sampling level. The background data was a bit patchy some years so assumptions for the data poor years needed to be done in the calculations.
There are length distributions available of commercial catches from Faroese commercial trawl and longliners fishing in 5.b (Figure 5). Age compositions from Faroese landings in Faroese waters were used in the assessment.
A closer look at a consistency plot of the catch number at age data showed that there were very few fish from longliners at age 6 in year 1999, age 7 in 2000 and age 9 in 2002. All these fish were from YC 1993.

Closer investigation of the input material showed that only one fish was aged for these ages these particular years. The solution to this problem was that samples were borrowed only for the years 1999, 2000 and 2002. This procedure only caused a minor modification in the data and a consistency plot of the final data is showed in Figure 6. A description of the data approach and the ALK-program is presented in the stock annex and in Appendix 2.

At the WKBARFAR benchmark it was agreed that the catch number at age for years 1996-2020 (Table 3) was adequate to use in the age-based assessment.

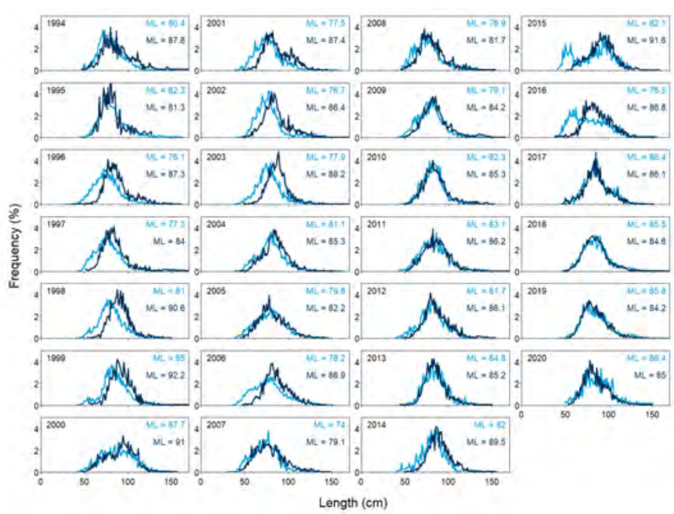


Figure 5. Ling in 5.b. Length distribution in the sampling of the landings from Faroese longliners (>110 GRT, light blue line) and the trawlers (> 1000 HP, dark blue line) (ML- mean length).

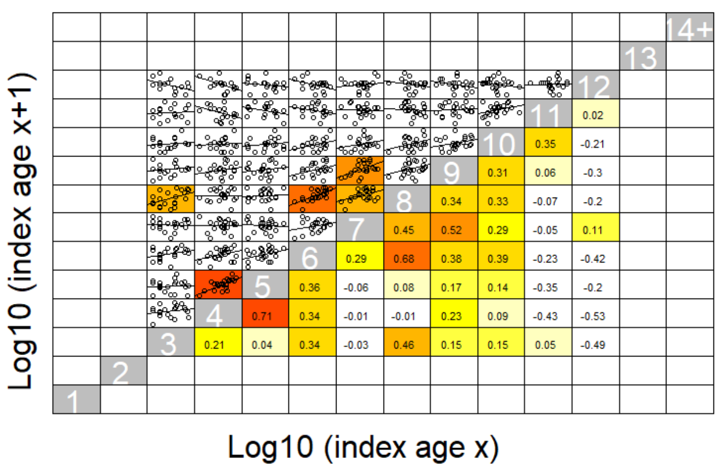


Figure 6. Consistency plot of catch numbers at age used in the assessment.

Table 3. Catch numbers at age (*1000) used in the assessment as agreed by WKBARFAR.

Year/Age	3	4	5	6	7	8	9	10	11	12+
1996	4.61	78.35	217.21	315.07	331.78	218.24	107.42	66.60	28.09	30.47
1997	0.55	6.75	146.07	238.84	402.52	390.43	257.69	129.96	30.65	46.49
1998	25.65	2.33	24.05	108.31	240.07	309.48	320.41	162.44	53.70	61.29
1999	22.75	7.35	22.63	74.23	167.75	257.56	306.70	178.02	79.40	63.87
2000	4.08	21.44	75.97	109.44	146.73	130.44	181.12	92.52	46.92	47.02
2001	1.72	13.75	22.35	215.75	540.89	193.18	116.06	68.42	33.26	44.27
2002	0.61	23.90	68.27	271.06	371.53	244.48	113.10	58.66	10.70	37.57
2003	1.52	25.89	64.96	302.49	453.02	371.62	189.99	76.46	21.85	44.53
2004	8.17	105.61	123.96	177.67	354.74	394.72	183.83	85.85	52.06	43.07
2005	13.02	48.96	121.94	271.20	293.16	340.27	204.43	98.64	46.65	59.31
2006	7.26	106.18	132.44	107.98	279.51	275.68	168.54	98.24	64.85	76.51
2007	18.96	134.46	122.59	276.73	372.36	299.89	113.57	72.91	22.21	33.42
2008	7.34	32.64	214.41	386.01	276.34	215.38	91.76	55.91	24.63	43.71
2009	2.49	40.18	69.00	168.71	328.79	295.46	164.51	136.75	19.61	42.54
2010	1.96	10.95	25.69	285.53	325.54	378.05	326.26	94.46	29.59	45.48
2011	2.76	17.90	82.28	189.47	276.87	238.35	180.57	98.56	36.85	37.23
2012	7.33	32.67	71.90	158.38	374.58	280.16	274.01	249.81	31.86	28.24

2013	0.53	4.75	37.42	137.06	261.82	246.96	171.52	83.66	31.18	21.83
2014	8.82	37.92	101.19	225.79	486.84	382.35	259.59	101.01	35.07	31.81
2015	18.28	75.68	161.86	170.67	205.68	207.57	240.45	146.60	52.78	30.18
2016	2.46	53.49	395.66	320.91	199.76	238.59	193.40	110.50	39.20	15.73
2017	0.21	22.12	139.53	305.36	403.18	210.10	147.90	105.84	50.66	15.70
2018	0.32	11.62	75.56	222.94	347.56	239.32	128.53	55.74	48.96	38.21
2019	0.43	1.43	50.59	193.19	458.31	405.07	337.82	155.72	79.56	100.16
2020	0.63	3.51	20.19	193.48	460.41	458.05	282.34	191.36	107.11	89.74

Plus group

The WKBARFAR agreed that the plus group should consist of ages 12 years and older (12+). 12+ constituted 2-6% in terms of numbers, but around 10-18% by biomass (Table 4). Even though it mattered by biomass there was not enough data to increase the ages in the plus group.

Table 4. Catch numbers at age and calculated weights at age as % in different plus groups.

	Catch numbers at age (%)					**Calculated weights at age (%)**				
	11+	**12+**	13+	14+	15+	11+	**12+**	13+	14+	15+
1996	4.2	**2.2**	1.4	0.8	0.4	12.7	**7.8**	5.3	3.2	1.7
1997	4.7	**2.8**	1.1	0.6	0.5	12.8	**8.6**	4	2.5	1.9
1998	8.8	**4.7**	2.2	1.7	0.7	18.3	**11.5**	6.4	5.4	2.6
1999	14.2	**6.2**	3.2	1.2	0.5	26	**13.9**	8.1	3.8	1.8
2000	10.9	**5.6**	2	1	0.4	22.6	**13.3**	5.3	2.8	1.4
2001	6.2	**3.5**	1.4	0.8	0.4	16.9	**11**	5.2	2.9	1.8
2002	4.6	**3.4**	1.8	1	0.4	14.6	**11.8**	7	4.1	1.8
2003	4.3	**2.9**	1.6	0.6	0.5	12.3	**9.2**	5.6	2.5	1.9
2004	6.2	**2.8**	1.8	1.1	0.6	17.1	**9.3**	6.6	4.2	2.6
2005	7.1	**4**	2.8	1.4	0.6	19.4	**12.8**	9.8	5.7	2.5
2006	10.7	**5.8**	3.5	1.6	0.8	28	**18.1**	12	6.1	3.2
2007	3.8	**2.3**	0.9	0.5	0.2	12.9	**8.7**	4.1	2.3	1.2
2008	5.1	**3.2**	1.9	1	0.5	16.4	**11.6**	7.4	4.1	2.2
2009	4.9	**3.4**	1.2	0.8	0.2	13.1	**9.8**	4.2	2.9	0.9
2010	4.9	**3**	1.7	0.6	0.2	13.3	**8.8**	5.5	2.1	0.8
2011	6.4	**3.2**	1.7	0.9	0.5	15.8	**9.6**	6	3.2	2
2012	4	**1.9**	0.8	0.4	0.2	9.8	**5.2**	2.7	1.5	0.7
2013	5.3	**2.2**	0.9	0.4	0.2	11.5	**5.5**	2.6	1.2	0.5
2014	4	**1.9**	1	0.5	0.2	9.7	**5.5**	3.1	1.7	0.9
2015	6.3	**2.3**	1.5	0.6	0.3	14.3	**6.5**	4.3	2	0.9
2016	3.5	**1**	0.3	0.1	0	9.7	**3.6**	1	0.5	0.1
2017	4.7	**1.1**	0.6	0.1	0	10.7	**3.2**	2	0.3	0.1
2018	7.5	**3.3**	1.5	0.2	0.1	18.1	**9.1**	4.6	0.8	0.6
2019	10.1	**5.6**	3.3	1.8	0.8	24	**15.8**	10.5	6.4	2.8
2020	8.4	**3.1**	1.5	0.9	0.6	17.6	**8.3**	4.7	3.1	2.2

Catch weights at age

The catch weights at age were calculated in the ALK-program (stock annex). The results showed no clear time trend and not much variability between years (Figure 7).

At the WKBARFAR it was agreed that the catch weights at age for the years 1996-2020 (Table 5) were adequate to be used in the assessment.

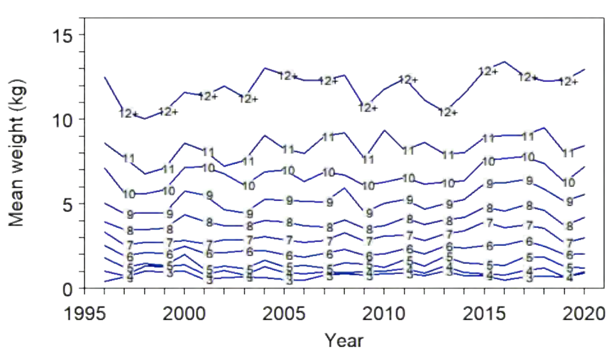


Figure 7. Weighted mean weights at age used in the assessment.

Table 5. Weighted mean weights at age used in the assessment.

Year/Age	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1996	0.437	1.033	1.815	2.549	3.356	3.949	5.054	7.143	8.600	12.509
1997	0.689	0.772	1.271	1.932	2.602	3.487	4.427	5.643	7.740	10.415

1998	1.038	1.345	1.469	2.112	2.728	3.500	4.486	5.599	6.786	10.064
1999	0.987	1.299	1.377	2.092	2.739	3.552	4.462	5.843	7.122	10.506
2000	1.037	1.402	2.005	2.517	2.855	4.374	5.775	7.157	8.622	11.587
2001	0.549	0.858	1.154	2.093	2.651	3.983	5.555	7.207	8.136	11.429
2002	0.660	1.081	1.351	2.146	2.888	3.728	4.665	6.798	7.239	11.995
2003	0.701	0.818	1.181	2.225	2.890	3.732	4.463	6.123	7.585	11.290
2004	0.654	1.292	1.674	2.251	3.093	4.042	5.271	6.923	9.080	13.031
2005	0.528	0.964	1.300	2.006	2.890	3.950	5.241	7.034	8.270	12.661
2006	0.495	0.876	1.378	1.867	2.719	3.710	5.145	6.323	7.987	12.332
2007	0.788	1.010	1.216	2.092	2.841	3.651	5.138	6.915	9.019	12.339
2008	0.872	0.942	1.534	2.317	3.295	4.070	5.944	6.713	9.197	12.625
2009	0.796	1.006	1.462	1.965	2.830	3.556	4.514	6.124	7.682	10.750
2010	0.897	1.049	1.248	2.072	3.133	3.730	5.066	6.311	9.372	11.798
2011	0.901	1.173	1.705	2.358	3.165	4.159	5.277	6.564	8.211	12.429
2012	0.770	0.929	1.342	2.043	2.845	3.804	4.716	6.169	8.646	11.149
2013	1.036	1.352	1.912	2.519	3.238	4.048	5.013	6.282	7.947	10.466
2014	0.765	0.963	1.540	2.400	3.424	4.225	5.275	6.356	8.056	11.528
2015	0.775	0.864	1.438	2.565	3.940	4.812	6.233	7.580	8.947	12.918
2016	0.500	0.805	1.364	2.585	3.610	4.575	6.269	7.711	9.064	13.436
2017	0.672	1.085	1.867	2.846	3.763	4.952	6.445	7.821	9.049	12.586
2018	0.735	1.231	1.878	2.516	3.578	4.632	5.886	7.411	9.537	12.299
2019	0.702	0.707	1.294	2.030	2.703	3.738	5.176	6.298	8.056	12.321
2020	0.930	0.995	1.205	2.062	3.013	4.206	5.585	7.200	8.462	12.949

Stock weights at age

At the WKBARFAR there were discussions whether catch weights at age or spring survey weights at age (Figure 8) should be used as stock weights at age. The spring survey had only aged data from 2013 to 2020, so the ages in 1998 to 2012 were "borrowed" and for the years 1996 and 1997 the average weights at age for the period 1998-2020 was used (Table 8). A closer investigation was done by doing an assessment in SAM with both alternatives and the results were similar with regards to SSB. Average weights at age for small fish were lower in the spring survey compared to the catch, probably due to gear selection. The reviewer said that the survey was better on first principles, but the WKBARFAR agreed on using catch weights at age for robustness. Catch weights at age is also used as stock weights at age for Faroe Plateau cod, Faroe haddock and Faroe saithe.

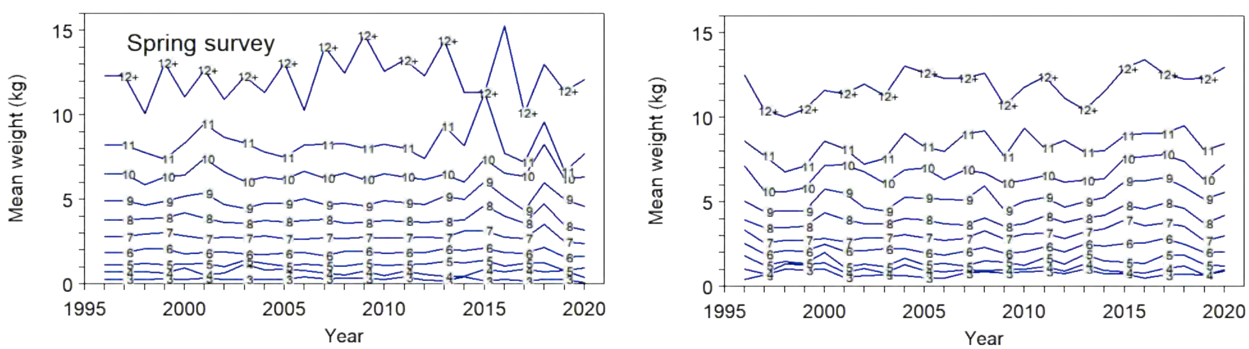


Figure 8. Spring survey weights at age (left) and weighted mean weights at age used in the assessment (right).

Natural mortality

The WKBARFAR agreed to set natural mortality to 0.15 (same as Icelandic ling).

Proportion mature at age

There are only data of ling maturation available since 2013 (Table 2). The recommendation from WGBIOP was to only use the maturity data collected during the spawning season or in a 3 month period before the spawning season. In Faroese waters the spawning season for ling is in the period April-June and according to this criterion data from January to June can be used for maturity. The maturity results for the whole year were compared with the maturity results for January to June, and there were minimal differences between the results (Table 6). Proportion mature compared between whole years are showed in Figure 9. As the sample size gets larger, the FAMRI recommends using the proportion mature with data from the whole year (and whole period) (Table 6, bold).

The WKBARFAR agreed on pooling the entire time series of maturity data so it is the same proportion mature for all years (Table 6).

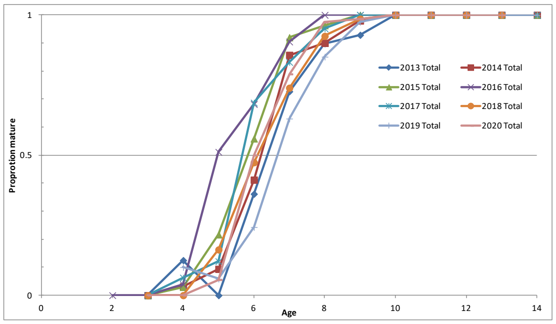


Figure 9. Proportion mature by age by year.

Table 6. Number of immature and mature ling by age and season.

Months	Area	Age	3	4	5	6	7	8	9	10	11	12	13	14+
Jan.- Dec.	Faroese waters	Immature	50	159	263	275	169	48	9	0	0	0	0	0
		Mature	0	6	61	278	623	644	519	353	173	91	43	23
		Proportion mature	**0.00**	**0.04**	**0.19**	**0.50**	**0.79**	**0.93**	**0.98**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Jan.- Jun.	Faroese waters	Immature	15	55	101	115	62	24	3	0	0	0	0	0
		Mature	0	4	31	130	299	332	256	174	90	50	26	6
		Proportion mature	0.00	0.07	0.23	0.53	0.83	0.93	0.99	1.00	1.00	1.00	1.00	1.00

Spring- and summer survey as tuning series

Catch-at-age data are provided for the Faroe Plateau spring- and summer groundfish surveys. There are lengths, round weights and ages available (Table 2). There is, however, a need to improve the sampling level. The background data was a bit patchy some years so assumptions for the data poor years needed to be done in the calculations. The two Faroe Plateau groundfish surveys were investigated whether they could be used as tuning series in the assessment (Figure 10).

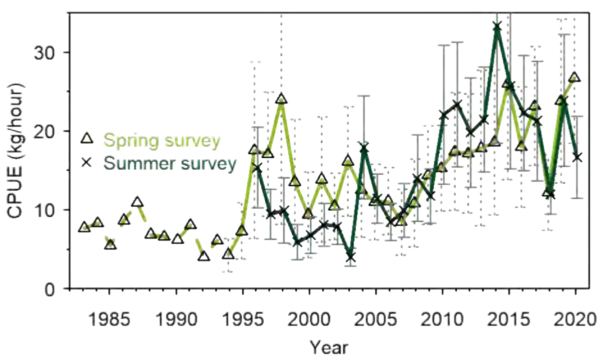


Figure 10. Abundance indices from the Faroe Plateau spring- and summer survey.

Spring groundfish survey

There were length distributions available annually from the spring survey (Figure 11). The small ling are often sampled from a subsample of the total catch, so the values are multiplied to total catch. In the catch at age calculations, 5 cm bins were used to smooth the lengths. Age compositions from the surveys in Faroese waters were used in the tuning series. The Faroese ALK-program was used in the calculations (stock annex, Appendix 2).

The consistency plot looked acceptable (Figure 12). This survey did not catch much of the very smallest fish, so there were very few fish at age 3. There were very few or no weight samples in 1994-1997 (Table 2) and weights at age are presented in Table 7.

The WKBARFAR agreed that the spring survey ages 4 to 11 and years 1998 to 2020 was adequate to be used as tuning series in the assessment (Table 8).

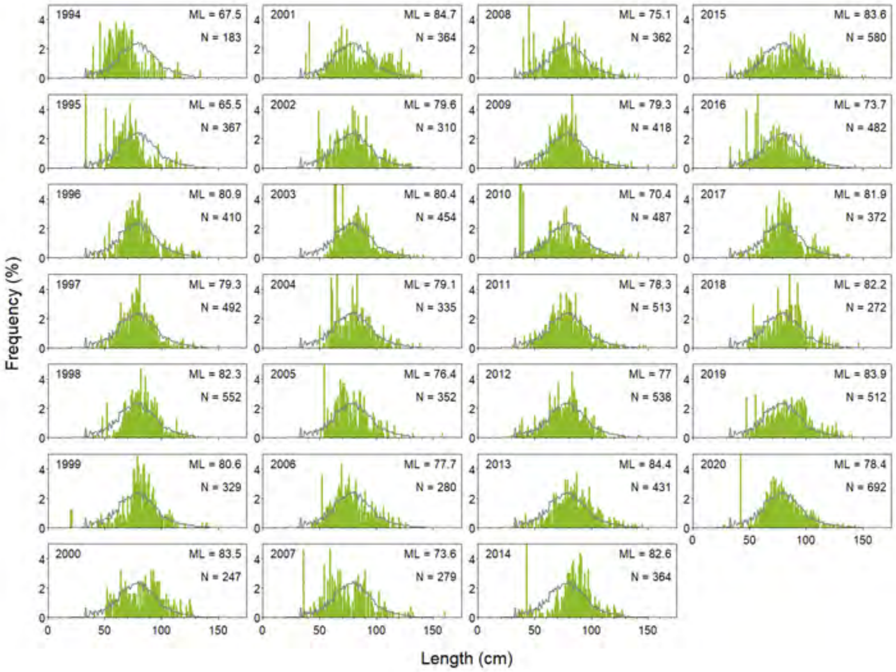


Figure 11. Ling in 5.b. Length distributions from the spring groundfish survey. ML- mean length, N- number of calculated length measures. The small ling are often sampled from a subsample of the total catch, so the values are multiplied to total catch. The grey line is the frequency for all years together.

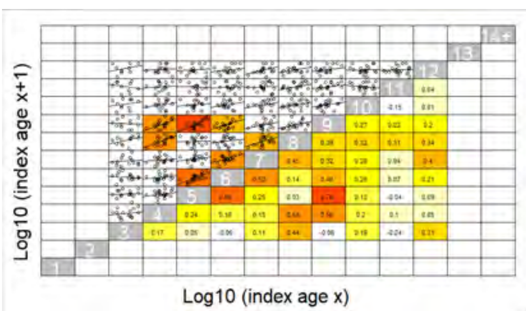


Figure 12. Consistency plot of the spring survey catch at age.

Table 7. Mean weights at age from spring survey. Grey values are average values.

Year/Age	3	4	5	6	7	8	9	10	11	12+
1996	0.291	0.710	1.162	1.882	2.812	3.812	4.950	6.514	8.248	12.314
1997	0.291	0.710	1.162	1.882	2.812	3.812	4.950	6.514	8.248	12.314
1998	0.255	0.719	1.210	2.097	2.950	3.856	4.668	5.883	7.777	10.090
1999	0.317	0.654	1.154	2.105	3.057	3.912	4.884	6.343	7.397	13.090
2000	0.291	0.957	1.173	1.774	2.860	4.197	5.213	6.448	8.330	11.058
2001	0.355	0.542	1.208	1.855	2.690	3.898	5.376	7.434	9.497	12.681
2002	0.291	0.665	1.021	1.886	2.777	3.627	4.690	6.641	8.693	10.923
2003	0.291	1.196	1.394	1.782	2.731	3.594	4.487	6.055	8.350	12.285
2004	0.291	0.823	1.226	1.749	2.838	3.752	4.767	6.344	7.832	11.331
2005	0.291	0.872	1.055	1.822	2.680	3.691	4.773	6.202	7.493	13.082
2006	0.413	0.797	1.164	1.863	2.671	3.749	5.057	6.684	8.215	10.272
2007	0.313	0.637	1.104	1.679	2.741	3.821	4.701	6.267	8.261	14.046
2008	0.337	0.522	1.066	1.923	2.698	3.624	4.790	6.563	8.300	12.490
2009	0.348	0.749	1.234	1.945	2.767	3.637	4.612	6.200	8.033	14.735
2010	0.290	0.494	1.100	1.823	2.745	3.764	4.916	6.508	8.269	12.604
2011	0.421	0.765	1.153	1.880	2.754	3.722	4.812	6.338	8.050	13.260
2012	0.250	0.584	1.174	1.848	2.758	3.647	4.701	6.180	7.447	12.305
2013	0.186	0.469	1.346	2.075	2.745	3.712	5.192	6.505	9.359	14.413
2014	0.413	0.481	1.243	1.966	3.146	3.790	5.028	6.028	8.181	11.330
2015	0.192	0.867	1.393	2.135	3.157	4.661	6.057	7.379	11.333	11.324
2016	0.275	0.721	1.062	1.848	2.763	4.020	5.176	6.580	7.740	15.274
2017	0.186	0.870	1.231	1.823	2.717	3.606	4.353	6.388	7.212	10.132
2018	0.291	0.745	1.240	2.164	3.542	4.750	6.010	8.262	9.580	12.989
2019	0.291	0.804	0.803	1.589	2.506	3.451	5.020	6.227	6.660	11.418
2020	0.101	0.394	0.965	1.646	2.382	3.202	4.575	6.354	7.688	12.082

Table 8. Spring survey input to the tuning series in the assessment.

Year	Effort/Age	4	5	6	7	8	9	10	11
1998	99	9.89	24.55	71.72	145.22	139.42	109.23	51.43	21.05
1999	100	9.32	17.96	39.25	81.76	79.70	61.73	32.54	11.70
2000	100	6.56	28.07	35.01	35.48	35.38	37.82	26.64	13.93
2001	100	24.58	33.24	54.15	57.28	37.88	32.66	28.81	22.10
2002	100	15.14	30.60	45.98	70.90	54.61	36.26	21.67	12.77
2003	100	2.10	33.42	101.31	126.24	98.29	61.98	27.26	12.56
2004	100	6.69	32.83	61.94	77.23	68.05	51.93	29.60	13.89
2005	100	21.42	66.62	75.03	82.55	55.15	39.79	21.59	9.09
2006	100	10.26	34.55	59.54	70.37	48.54	38.40	27.83	14.98
2007	100	27.50	51.54	55.93	49.14	39.00	29.58	14.88	7.01
2008	99	32.19	32.12	50.88	72.16	49.44	35.93	22.52	12.70
2009	100	12.53	38.37	83.48	115.08	77.42	48.14	22.83	10.35
2010	100	56.82	63.62	82.75	90.90	66.86	51.17	31.64	16.06
2011	102	23.41	67.54	108.40	131.17	91.45	62.01	32.31	13.43
2012	100	23.31	47.92	95.85	131.63	101.62	69.24	36.49	13.89
2013	100	9.97	17.30	70.18	95.52	99.77	60.88	49.70	23.41
2014	99	24.90	9.11	28.35	81.17	106.26	86.14	54.74	16.70
2015	96	69.48	101.31	53.80	76.77	143.87	106.13	14.00	7.62
2016	100	52.22	94.11	163.49	109.75	68.63	51.51	32.53	20.20
2017	90	11.96	25.69	65.83	157.08	124.76	45.87	45.23	23.65
2018	99	11.88	35.88	55.86	87.03	60.08	27.86	11.99	12.39
2019	100	9.12	69.58	77.89	87.17	106.18	137.35	56.81	22.55
2020	91	21.93	39.91	147.74	198.27	116.33	115.87	60.55	25.11

Summer groundfish survey

There were length distributions available annually from the Faroe Plateau summer survey (Figure 13). The small ling are often sampled from a subsample of the total catch, so the values are multiplied to total catch. In the catch at age calculations, 5 cm bins were used to smooth the lengths. Age compositions from survey in Faroese waters were used in the tuning series. The Faroese ALK-program was used in the calculations (Stock Annex, Appendix 2).

The final consistency plot showed that the series was very usable (Figure 14). A minor correction was done because very few age samples were available (of age 3 and 4 in year 2019 and 2020 in summer survey). Samples were borrowed from 4 stations in the summer survey 2018 that contained ages 3 and 4, so this was the same solution as in the correction of the catch at age data. Weights at age is presented in Table 9.

The WKBARFAR agreed that the summer survey ages 3 to 11 and years 1996 to 2020 was adequate to be used as tuning series in the assessment (Table 10).

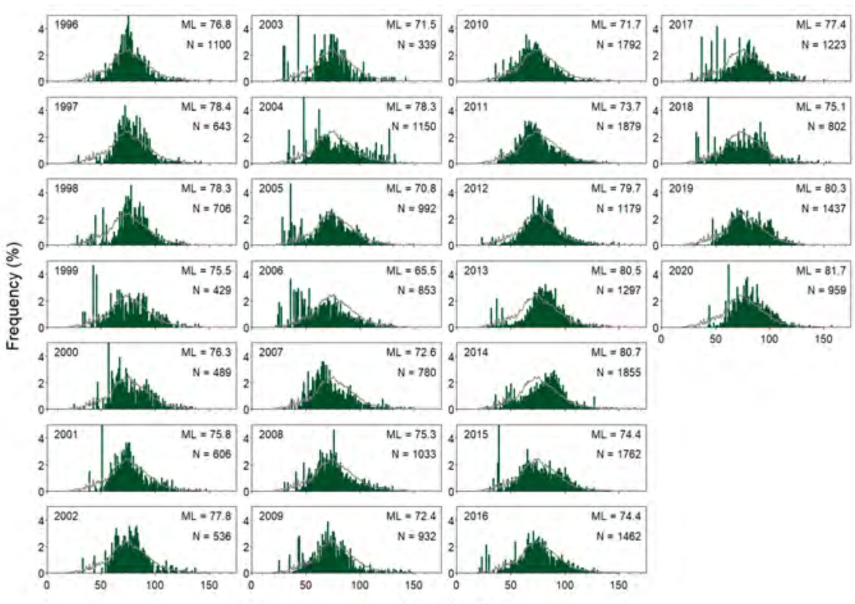


Figure 13. Ling in 5.b. Length distribution from the summer groundfish survey (ML- mean length, N- number sampled). The grey line is the frequency for all years together.

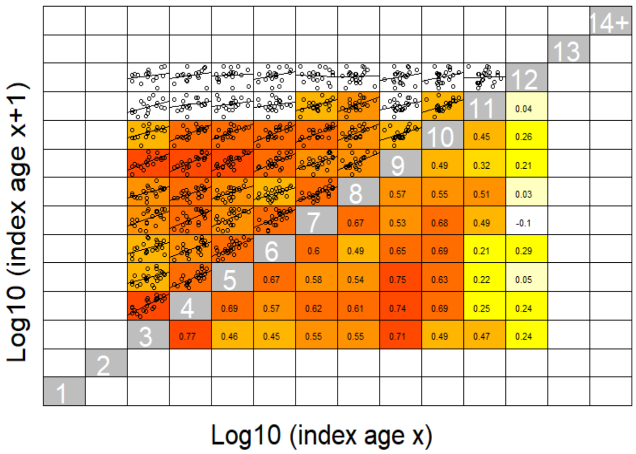


Figure 14. Consistency plot of the summer survey catch at age.

Table 9. Mean weights at age from the summer survey.

Year/Age	3	4	5	6	7	8	9	10	11	12+
1996	0.547	0.790	1.467	1.974	2.524	3.231	4.154	5.480	7.339	10.597
1997	0.378	0.818	1.471	1.916	2.594	3.346	4.113	5.374	7.643	9.454
1998	0.367	0.659	1.458	2.101	2.727	3.451	4.338	5.529	7.261	8.987
1999	0.472	0.631	1.306	1.855	2.731	3.529	4.638	5.939	7.212	9.634
2000	0.578	0.878	1.355	1.813	2.625	3.662	4.741	5.926	7.467	10.188
2001	0.487	0.878	1.281	1.900	2.520	3.265	4.500	5.984	7.268	9.474
2002	0.328	0.733	1.389	1.896	2.618	3.259	4.132	5.816	7.719	9.966
2003	0.278	0.574	1.369	1.935	2.580	3.245	4.259	5.831	7.455	10.676
2004	0.419	0.646	1.317	1.764	2.613	3.524	4.636	6.220	7.885	10.091
2005	0.319	0.555	1.338	1.843	2.520	3.379	4.477	5.502	6.997	9.622
2006	0.390	0.602	1.163	1.741	2.492	3.346	4.469	5.932	7.599	9.496
2007	0.471	0.774	1.239	1.688	2.421	3.409	4.422	5.835	7.900	11.327
2008	0.444	0.743	1.317	2.337	2.474	3.943	5.451	6.516	8.133	10.423
2009	0.461	0.624	1.371	1.920	2.628	3.387	4.320	5.821	7.896	12.322
2010	0.451	0.708	1.350	1.846	2.515	3.379	4.466	5.698	7.520	12.014
2011	0.529	0.800	1.333	1.806	2.477	3.361	4.502	5.731	7.252	10.663
2012	0.394	0.767	1.457	2.063	2.756	3.445	4.453	5.949	7.630	11.546
2013	0.332	0.378	1.142	1.950	2.761	3.630	4.585	5.629	8.649	11.952
2014	0.513	0.699	1.373	1.859	2.607	3.649	4.449	5.102	7.881	12.644
2015	0.288	0.744	1.415	2.134	3.053	3.466	4.951	6.189	6.339	9.729
2016	0.188	0.713	1.363	2.041	2.798	3.653	4.798	6.036	8.160	11.580
2017	0.383	0.672	1.172	2.121	3.043	4.157	5.023	7.608	8.360	11.379
2018	0.323	0.587	1.357	2.219	3.373	4.175	5.409	7.427	8.969	15.405
2019	0.282	0.680	0.858	1.536	2.420	3.143	4.311	5.182	6.738	8.311
2020	0.425	0.890	1.185	1.700	2.570	3.313	4.807	5.383	7.241	9.561

Table 10. Summer survey input to tuning series in the assessment.

Year	Effort/Age	3	4	5	6	7	8	9	10	11
1996	200	11.38	39.70	111.95	256.77	300.86	185.77	98.00	45.83	17.95
1997	200	4.94	13.89	61.94	140.89	168.21	128.83	73.46	29.36	11.85
1998	201	20.92	38.21	45.48	114.95	168.79	133.77	83.41	39.23	14.09
1999	199	18.93	47.30	46.45	61.87	68.93	58.80	43.86	29.08	13.34
2000	200	4.89	25.12	73.80	95.02	81.32	61.06	50.79	31.30	12.60
2001	200	8.27	45.07	92.59	131.29	135.02	78.89	46.75	32.41	17.82
2002	199	6.10	18.48	63.43	113.29	136.87	99.41	48.59	23.73	12.67
2003	200	21.61	29.24	39.10	65.24	73.98	45.50	22.43	11.78	5.36
2004	200	48.54	97.79	139.48	184.82	167.07	133.66	106.36	79.13	51.71
2005	200	106.85	95.08	101.27	171.28	176.16	122.33	89.16	50.75	18.26
2006	200	93.25	155.98	111.89	122.50	111.92	75.77	51.65	33.39	17.12
2007	199	25.15	88.26	168.60	189.28	135.89	84.28	56.02	30.35	13.32
2008	200	22.87	78.03	204.72	349.54	111.51	78.49	72.37	34.51	22.90
2009	200	52.94	121.59	117.20	184.95	188.36	124.15	63.02	28.61	12.40
2010	200	81.20	179.96	302.53	436.20	378.24	216.37	123.76	59.79	20.05
2011	200	36.65	146.14	327.38	451.03	376.30	221.33	141.50	81.09	32.33
2012	202	14.74	36.49	102.95	221.93	316.95	240.56	137.37	71.99	33.48

2013	202	52.95	28.43	42.21	224.36	330.64	312.16	157.45	105.37	26.94
2014	200	78.55	125.02	142.89	140.83	258.05	557.88	281.63	175.20	65.24
2015	200	119.36	145.39	420.17	242.21	215.94	240.78	253.17	85.59	65.09
2016	199	60.14	116.01	222.53	358.31	275.61	178.93	147.10	111.26	24.05
2017	203	57.55	118.45	148.43	271.06	299.32	165.99	74.49	80.68	43.59
2018	202	41.65	109.80	129.74	98.40	226.02	93.65	35.76	32.80	29.95
2019	200	4.90	43.91	75.89	310.24	360.70	194.83	249.01	133.51	88.56
2020	199	9.98	22.31	29.98	156.65	320.24	218.20	112.55	106.64	39.00

Stock abundance series from commercial fleets

Standardized CPUE from longliners and trawlers (bycatch) series for the years 1996-2020 were presented at the WKBARFAR (Figure 18). The standardization is described in Stock Annex. Even though there were no striking problems detected with the commercial tuning series (in terms of series trends or problems arising from aggregating fish or fishery targeting) the WKBARFAR benchmark decided not to use the commercial series in the tuning of the assessment model.

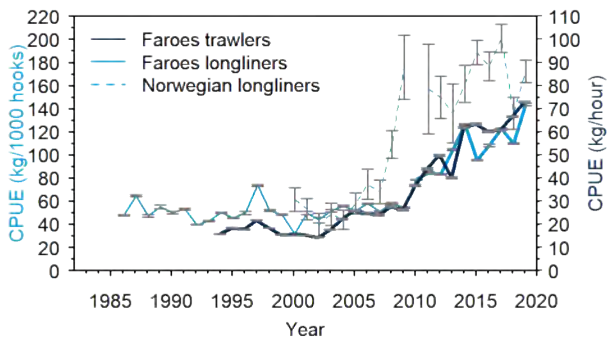


Figure 15. Standardized CPUE from commercial fleets.

An ALK program to compute age-disaggregated fish based on age-measured and "only-length" measured fish

Faroe Marine Research Institute (FAMRI)
Sólva Eliassen, Ebba Mortensen, Petur Steingrund, Lise H. Ofstad and Eydna í Homrum

1. Introduction

Annual stock assessment is performed for several fish stocks, by several fish biologists at FAMRI, and therefore it is necessary to have a standardized method, by which fish samples are used to estimate the total number of fish and their age-distribution, both in commercial catch and in scientific surveys.

Previously a program (BALK) was available at FAMRI, which worked together with the Biohag database to carry out the ALK (Age Length Key) computations. Also, a few of the scientists used their own R-scripts or several excel sheets to do the ALK computations.

After the upgrade of the Biohag data base in 2018 (now called Unnur database), it was not possible anymore to use BALK, which was developed around 2000. The ALK 2019 program is a successor to this program and was developed in close co-operation with the scientists performing the stock assessments.

In addition, this ALK program can calculate the ALK to use from the annual spring- and summer survey (tuning series), using stratification. That is a replacement of the MALK program (using the information from the survey database called Magnus), which was mainly designed to cod, haddock and saithe and/or for excel to do the ALK computation.

This new ALK program can be used for data from both commercial fisheries and distinct surveys. In addition, in the ALK program when a length group miss ages, ages can be "borrow" from years around the actual year, so it is possible to calculate a catch number of age for fish species that do not have a huge amount of ages.

2. Program description

The program calculates age distribution in fish samples from a catch, models a length-weight relationship based on the fish in the samples, and, combining these two, computes the age-distribution and number of fish in the catch.

2.1 General method

The samples, used in the ALK program contain both age-measured fish and "only-length" measured fish. The fish are first disaggregated in an ALK table. In addition to that, there are the "only-length" measured fish, which are sorted into length intervals.

Row	a0	a1	a2	a3	a4	a5	aldrar	bert_l	longdir
L7-L9	0	20	0	0	0	0	20	17	37
L9-L11	0	16	4	13	1	0	34	87	121

L11-L13	0	1	2	93	1	1	98	136	234
L13-L15	0	0	0	3	1	1	5	16	21
tal	0	37	6	109	3	2	157	256	413
miðal_l	NaN	9.02	11.20	11.64	12.37	12.90	11.03	11.09	11.07
sdev_l	NaN	0.99	0.85	0.60	1.82	2.12	1.37	1.36	1.36

"Only-length" measured fish in the samples are assigned ages depending on the age-distribution of other fish in the same length interval or based on a normal distribution applied to all fish in each age, see below. From ALK, AL, which is the ratio of ages in each length group, is computed:

$$AL_{ij} = ALK_{ij} \frac{1}{\sum_j ALK_{ij}}$$

Example:

$$AL = \begin{bmatrix} \frac{0}{20} & \frac{20}{20} & \frac{0}{20} & \frac{0}{20} & \frac{0}{20} & \frac{0}{20} \\ \frac{0}{34} & \frac{16}{34} & \frac{4}{34} & \frac{13}{34} & \frac{1}{34} & \frac{0}{34} \\ \frac{0}{98} & \frac{1}{98} & \frac{2}{98} & \frac{93}{98} & \frac{1}{98} & \frac{1}{98} \\ \frac{0}{5} & \frac{0}{5} & \frac{0}{5} & \frac{3}{5} & \frac{1}{5} & \frac{1}{5} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0.47 & 0.12 & 0.38 & 0.03 & 0 \\ 0 & 0.01 & 0.02 & 0.95 & 0.01 & 0.01 \\ 0 & 0 & 0 & 0.6 & 0.2 & 0.2 \end{bmatrix}$$

Based on these ratios, the "only-length" measured fish (column "bert_l" in the ALK-table) are assigned ages and all fish are now summed up in an ALD-table:

$$ALD = ALK + AL * bert\_l$$

Example:

$$ALD = \begin{bmatrix} 0 & 20 & 0 & 0 & 0 & 0 \\ 0 & 16 & 4 & 13 & 1 & 0 \\ 0 & 1 & 2 & 93 & 1 & 1 \\ 0 & 0 & 0 & 3 & 1 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0.47 & 0.12 & 0.38 & 0.03 & 0 \\ 0 & 0.01 & 0.02 & 0.95 & 0.01 & 0.01 \\ 0 & 0 & 0 & 0.6 & 0.2 & 0.2 \end{bmatrix} .* \begin{bmatrix} 17 & 17 & 17 & 17 & 17 \\ 87 & 87 & 87 & 87 & 87 \\ 136 & 136 & 136 & 136 & 136 \\ 16 & 16 & 16 & 16 & 16 \end{bmatrix}$$

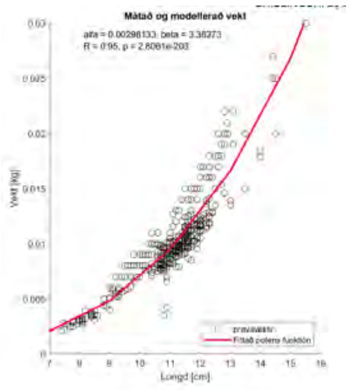
$$ALD = \begin{bmatrix} 0 & 20 & 0 & 0 & 0 & 0 \\ 0 & 16 & 4 & 13 & 1 & 0 \\ 0 & 1 & 2 & 93 & 1 & 1 \\ 0 & 0 & 0 & 3 & 1 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 17 & 0 & 0 & 0 \\ 0 & 40.9 & 1.2 & 2.6 & 0 \\ 0 & 1.4 & 136 & 136 & 1.4 \\ 0 & 0 & 0 & 9.6 & 3.2 \end{bmatrix}$$

Row	a0	a1	a2	a3	a4	a5	aldrar
L7-L9	0.0	37.0	0.0	0.0	0.0	0.0	37
L9-L11	0.0	56.9	14.2	46.3	3.6	0.0	121
L11-L13	0.0	2.4	4.8	222.1	2.4	2.4	234
L13-L15	0.0	0.0	0.0	12.6	4.2	4.2	21
tal	0.0	96.3	19.0	280.9	10.1	6.6	413

Based on the relationship between lengths (cm) and weights (gr):

$$W = \beta \cdot \log(L) + \log(\alpha)$$

a regression is made.



Thus, weights can be assigned to each of the length- and age intervals, and based on this, the number of fish in the catch (e.g. 100 tonnes) can be computed, which gives a distribution of age-disaggregated fish in the catch:

In addition to assuming that the "only-length" measured fish have the exact same age distribution as the age-measured fish, the program also computes a normal distribution of the lengths in each age, which then is applied to all the sampled lengths.

All results are saved in one folder. Relevant tables are saved as csv-files and a text-file with all input- and output results is also produced. Relevant figures, such as length-, age-, and weight distribution, are also saved in this same folder.

2.2 Special cases

2.2.1 Length intervals with no age-read fish

In cases where there are length-intervals with no age-read fish, but with length-measured fish, these fish disappear in the calculations if no special measures are taken. In this case there are rows in the AL-matrix with only zeros, and thus the total number of fish in the ALD matrix is less than the number of fish in the original samples:

There are three different ways that these fish can be assigned ages:

1. Using the age-distribution in background material to age-determine these length-measured fish.
2. Changing the length-intervals, such that there are no length intervals without any age-read fish
3. Using the results from the normally distributed age-distributions. This is automatically done when the computations are saved and the result files can be found in the output folder. This method automatically preserves all fish in the samples.

Using background material to assign ages to "only-length" measured fish

Taking advantage of other samples, either sampled by different equipment, different period or different area, or different year, age distributions from these are padded into the AL-matrix.

Changing the length-intervals

Changing the length-intervals is sometimes a sufficient solution in the upper end of the length distribution, where the oldest and longest fish are found. However, this is not a good solution for young and short fish, since these are likely to be assigned wrong ages.

Using the normally distributed results

Using the normally distributed results is always an option. The normal distribution is computed in each age group. However, fish, in length intervals with no age-read fish, will in the normally distributed results only be assigned ages that are already present in the dataset. E.g. the user should be cautious when there are small fish in the sample that are not age-read, because these will automatically be assigned other ages already in the dataset, which easily could be too old.

The user must in these cases check that the results in his/her opinion sufficiently well reproduce the distribution originally seen in the samples.

2.2.2 "Only-length" measured fish in the samples that are longer than the longest age measured

When this is the case, these fish are automatically assigned the highest age that any fish in the samples has.

2.3 Area stratification

Area stratification is only an option in the special case where only samples from scientific catch are in the ALK-computations. In this case, the user can check the "stratification" box. This area stratification is applied on the length distribution (number of fish of certain lengths) of fish and termed the "stratified length-distribution".

When calculating the **stratified length distribution** and **stratified ALD**, the method is as following:

- For each strata, the fish are sorted according to their lengths (the table "Mátaðar longdir í hvørjum strata")
- The fish in each strata are then divided by the number of trawl stations and multiplied by the number of squares (in the respective strata), which yields "Number of fish pr length interval pr strata" (the table "Longdir í hvørjum strata")
- Adding these fish up yields the total number of fish pr length interval on the whole shelf (the column "longdir" in the table "Longdir í hvørjum strata")
- The number of fish pr length interval pr square (**i.e. the stratified length distribution**) is then computed as the total number of fish pr length interval, divided by the total number of squares (the column "lprPunt" in the table "Longdir í hvørjum strata")
- All age-read fish in the whole survey are collected in an ordinary ALK table in order to calculate the age-distribution in each length interval for the whole survey
- The age-distribution in each length interval (the ALK-table) is then used to assign ages to the fish in the **stratified length distribution**, yielding the **stratified ALD distribution** for the whole survey.
    - This operation is done both with and without application of a normal distribution, yielding both a normally distributed ALD and an ALD which precisely reflects the observed age-distribution in each length interval.
- The total number of fish in the **stratified ALD** is found by multiplying the number of fish in all length intervals in each square (i.e. the total sum of the column "lprPunt" in the table "Longdir í hvørjum strata") by the number of trawl stations.

The final results are a weighted age-distribution and number of fish, according to the stratification.

The usual stratification of the Faroese spring- (100 stations) and summer (200 stations) survey on the Faroe Plateau is illustrated in the Figure 1. The Plateau is divided in 15 strata where each stratum has stations in the different squares. The main stratification is done using depth curves and orientation from land (to the North, East, South or West).

Strata	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Squares	45	30	21	12	25	44	62	58	56	39	24	33	21	34	38	542
Spring survey stations	14	4	6	4	6	4	15	6	5	7	4	11	4	7	3	100
Summer survey stations	20	10	11	7	11	10	25	18	10	16	8	17	11	17	9	200

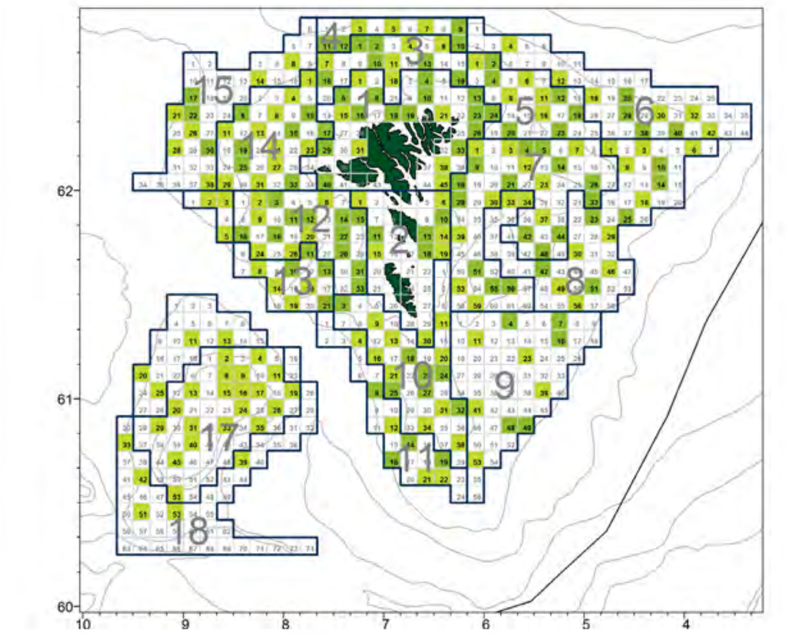


Figure 1. Overview of the stations on the Faroe Plateau in the 15 strata in the annual groundfish survey in spring (100 stations, dark green squares) and in summer (200 stations, dark green + light green squares). In addition the stations on the Faroe Bank survey (29 stations, light green squares in strata 17 and 18).

3 How to use the program

3.1 Input

An example of the possibilities and input parameters of the ALK program are showed in Figure 2 and 3.

Working folder ("Mappa")

The working folder is the path to the folder, where the folder, with data from the computations, is stored.

Folder name to store the data in

It's advisable to name the folder that the data from the calculations will be stored in as the run, e.g. Cod_2019_q1_2.a

Species ("Fiskaslag")

Choose for which species the ALK calculations should be carried out for.

Fleet name ("Drift")

DRIFT	LYSING	Description
0	Rannsóknarskip	Research vessel
1	Opnir bátar, lína	Open boats, longliners
2	Opnir bátar, snella	Open boats, jiggers
4	Línubátar 0-25 BRT	Longliners 0-25 GRT
5	Línubátar 25-40 BRT	Longliners 25-40 GRT
6	Línubátar 40-60 BRT	Longliners 40-60 GRT
7	Línubátar 60-100 BRT	Longliners 60-100 GRT
8	Garnabátar 0-100 BRT	Gillnetters 0-100 GRT
9	Snellubátar 0-100 BRT	Jiggers 0-100 GRT
10	Smáir lemmatrolarar 0-400 HK	Small single trawlers 0-400 HP
11	Smáir lemmatrolarar 400-700 HK	Small single trawlers 400-700 HP
12	Smáir lemmatrolarar 700-1000 HK	Small single trawlers 700-1000 HP
13	Millumstórir lemmatrolarar 1000-1500 HK	Medium single trawlers 1000-1500 HP
14	Størri lemmatrolarar 1500-2000 HK	Large single trawlers 1500-2000 HP
15	Djúpvatnstrolarar 2000- HK	Deepwater trawlers 2000- HP
16	Smáir partrolarar 0-400 HK	Small pair trawlers 0-400 HP
17	Smáir partrolarar 400-700 HK	Small pair trawlers 400-700 HP
18	Smáir partrolarar 700-1000 HK	Small pair trawlers 700-1000 HP
19	Størri partrolarar 1000-1500 HK	Large pair trawlers 1000-1500 HP
20	Størri partrolarar 1500-2000 HK	Large pair trawlers 1500-2000 HP
21	Størri partrolarir 2000- HK	Large pair trawlers 2000- HP
22	Stál línuskip 100- BRT	Stern longliners 100- GRT
23	Stál garnaskip 100- BRT	Stern gillnetters 100- GRT
24	Stál snelluskip 100- BRT	Stern jiggers 100- GRT
26	Íðnaðar flóti- og partrol	Industry pelagic- and pair trawlers
28	Nótabátar (kraftblokkur)	Seiners (power block)
30	Rækjutrol	Shrimp trawlers
31	Íðnaðarbotntrol	Industry bottom trawlers
32	Bátur (0-25) BRT	Boats (0-25) GRT
34	Teinir	Fishing pots
35	Skeljadregg	Shell dregg

Period and year ("Tíðarskeið og ár")

Assign which period (months of the year) and year span the program should run for.

Area ("Øki")

Assign which ICES area (e.g. 27.5.b.1, 27.5.b.2) the program should run for.

Samples ("Støð/Sýni")

After selecting the parameters above (species, fleet, period and area), the samples shown are all available samples from the specified period, fleet and area. Usually all would be selected.

Additional samples ("Eykasýni")

This category shows all other samples of the same species that are sampled in other areas, in other periods and with other fleets. The user can select how many years prior to, or after, the actual year should be used in the calculations. If zero is chosen, all samples, from the same year are shown. It's also possible to choose only from the same area, and/or same fleet, and/or same period, and/or only aged fish.

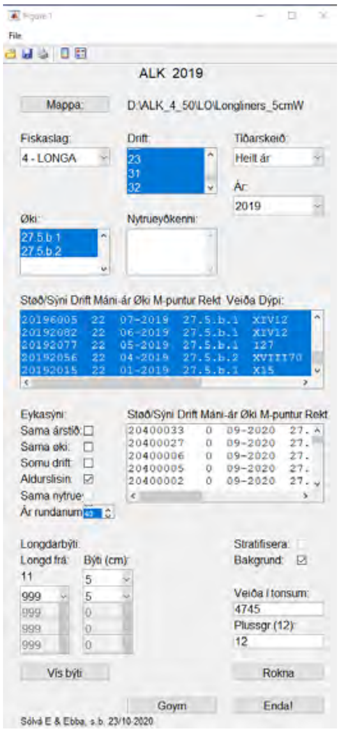


Figure 2. User interface for input data. Here the user chooses which samples to use, sets up length intervals, chooses whether or not other available samples should be used as age distribution in length intervals without any age-read fish, chooses whether or not stratification should be applied (only applicable with scientific samples), can plug in the total catch which the ALK should be applied on, and allows the user to point to a folder on the PC, where the work should be saved.

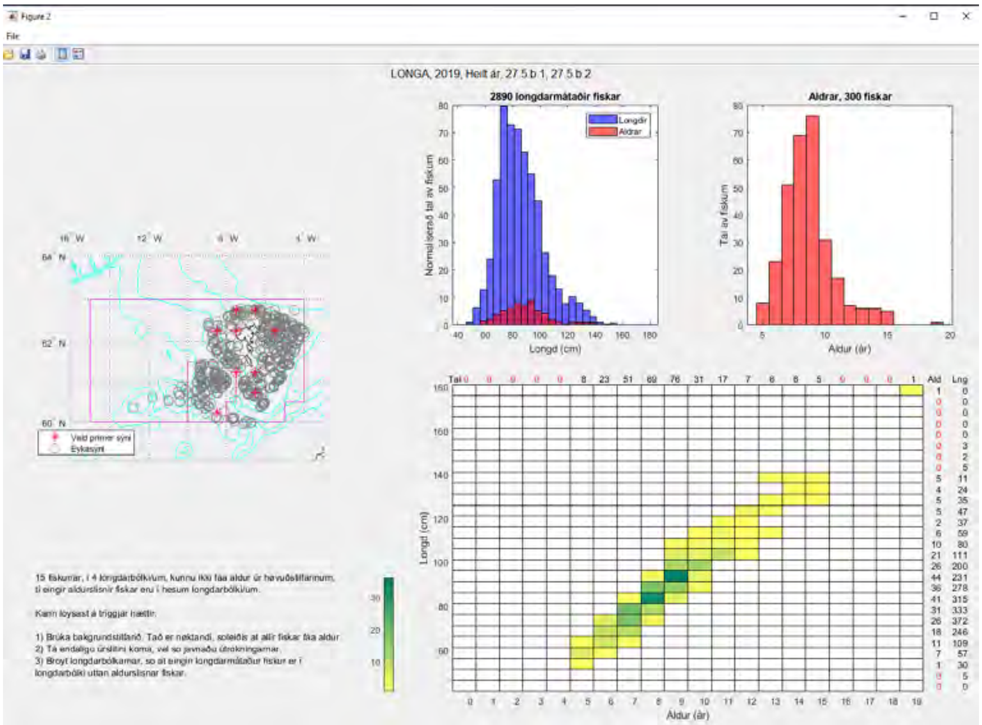


Figure 3. Overview of the chosen samples. This plot comes up when the user pushes the "Show distribution"-bottom ("Vís býti"). It gives an overview over the fish in the chosen samples and how many fish can be given age based on the ages available in the samples and gives a basis for deciding whether or not to proceed with the computations or to go back and change the samples-selection.

4 Output

All output is automatically stored in a folder which the user specifies when starting the program. These output files are stored:

- File with all input parameters (i.e. date, sample-number, number of fish, etc).
- Parameters from the computations (regression parameters, alpha, beta, rho and p, etc.).
- Separate csv-files with tables from the computation (two of each of these (with and without Normal distribution) ALK, ALD, Final results).
- File with all results compiled together.
- Plots of relevant parameters (lengths-distribution, age-length distribution, distribution of catch, etc.) (Figure 4).

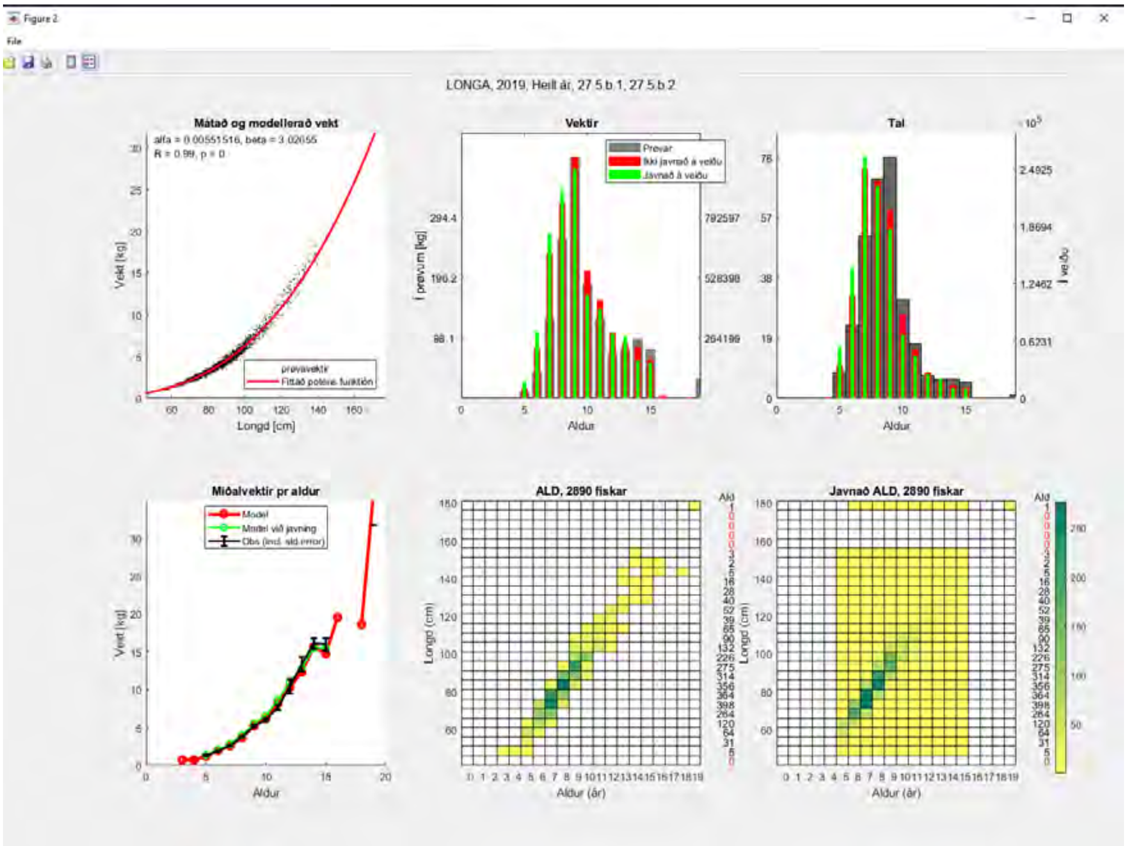


Figure 4. Results of the ALK-computations. This plot comes up when the user pushes the "Calculate"-bottom ("Rokna"). Displayed is the weight-modelling, the age-distribution in the total catch (or the scientific "catch") and the age-length distribution in the total catch, both as normally distributed and a direct reflection of the age-length distribution in the samples.

5 Ling 5.b

The results of ling from the ALK program are used in the benchmark stock assessment in November 2020/ February 2021 of this species. The background data is stored in a database at the Faroe Marine Research Institute. For ling, a plus group of age 12+ is used, where less than 10 % of the ages are in.

Several different settings were tried and the best result was when the lengths for the whole year were pooled and that can be done because of small growth difference in the year and the sample amount was higher. Here will the settings of the use of no length grouping in the ALK program and the use of 5 cm length group in the program As the number of ages differs from year to year and in some periods there are no or very little data, the settings of "borrow" data was used. So, in order to get enough material, as there are fish that cannot get an age from the material that particular year, it is possible to lend ages from the surrounding years. The age read fish have always length and a subsample is also weighted. An example from the program using longliners is showed in Figures 3-4.

Settings in the ALK program for commercial catch:
Working folder (Mappa) e.g. d:\ALK_4_50\LO\Longliners_5cmWholeYear\
Folder name to store the data in (Uppgava) e.g. 2011
Species (Fiskaslag) e.g. 4 - longa (ling)
Fleet name (Drift) e.g. 14, 18, 19 trawlers
Period (Tíðarskeið) and year (Ár) e.g. whole year (Heilt ár) and 2011
Area (Øki) e.g. 27.5.b
Samples e.g. select all available samples from the specified period, fleet and area.
Additional samples e.g. Age read (Aldurslisin) and year around (Ár rundanom) 1 or so many that all lengths have ages. Here all age read data area used.

The catch at age to use is the sum of catch number at age from longliners + trawlers.

The mean weight at age is the weighted mean; (sum of calculated weight for longliners + trawlers) divided by (sum of catch number at age for longliners + trawlers).

At the DCWK meeting, the required consistency plot some distinct outliers showed up. A closer investigation of this showed that there was only one age behind the data point. These outliers were corrected by borrowing samples for those actual years for longliners. So, for year 1999 samples are borrowed from longliners 1998, year 2000 samples are borrowed from longliners 2001, year 2002 samples are borrowed from longliners 2003. The samples are borrowed from the year with the closest comparable length distribution. The corrected results are presented here.

Settings in the ALK program for surveys:
Working folder (Mappa) e.g. d:\ALK_4_50\LO\SummerSurvey_5cmWholeYear\
Folder name to store the data in (Uppgava) e.g. 2011
Species (Fiskaslag) e.g. 4 - longa (ling)
Fleet name (Drift) e.g. 0 surveys
Period (Tíðarskeið) and year (Ár) e.g. period 21-Feb-2019 to 18-Mar-2019
Area (Øki) e.g. 27.5.b
Samples e.g. select all available samples from the specified period, fleet and area.
Additional samples e.g. Age read (Aldurslisin) and year around (Ár rundanom) 1 or so many that all lengths have ages. Here all age read data area used.

The surveys were stratified according to the 15 strata on the Faroe Plateau (see stock annex).

Updated 12 February 2021

Data series on recreational and tourist fisheries for Norwegian Coastal Cod

by

Kjell Nedreaas, Keno Ferter, Jon Helge Vølstad, Håkon Otterå and Asgeir Aglen

Institute of Marine Research, PB-1870, N-5817 Bergen, Norway

1. Background

Recreational fishing in saltwater is popular among the population in Norway, with the highest proportion participation of all countries in Europe. In addition, over time there has been a growth in tourist fishing in this country. In the following, we use the term marine recreational fishing (MRF) to cover recreational and tourist fishing in the sea. MRF can be divided into two main components; recreational fishing performed by residents, and tourist fishing where foreign tourists or residents fish from a tourist fishing facility, cottage, or other residences away from home.

ICES Arctic Fisheries WG (AFWG) includes in its annual reports an estimate of the amount of coastal cod fished in the tourist fishery and the Norwegian recreational fishery north of 62N. This is an estimate based on a WD (no. 17) by Knut Sunnanå, IMR, to AFWG in 2010 (AFWG 2010):

There are no measurements of the amount of Norwegian coastal cod (NCC) taken by recreational or tourist fishers in Norway. However, there are a few reports trying to assess the amount at certain years and these reports has been used to construct time series based on assumptions made in the reports of temporal trends.

Raising these figures to numbers caught at age is done by assuming that most of these catches are taken by hook and that the distribution of numbers at age for hook and longline is the most relevant data set to be used to split the data series.

Norwegian recreational fisheries

A survey for mapping recreational fisheries was conducted in 2003 (Hallenstvedt and Wulff, 2004) and the results from this report gave reason to assume that there were fished approx. 13 000t of cod by recreational fishers in 2003 north of 62°N. This was based on 50% of the catches in the area being cod and that due to the fishing season almost all of the cod was coastal cod.

The effort used in recreational fisheries was monitored through surveys of questionnaires mapping the amount of the population that had conducted recreational fisheries during the last year and to what extent it had been in saltwater or in lakes and rivers. Based on interpolating these surveys to the development of the population in Norway, it was possible to give an index of effort in recreational fisheries in the sea. It was assumed that recreational fisheries were conducted to catch a desired amount of fish – and that the effort was not restricted in time. This gave the quantity taken to be proportionate to the effort – and not influenced by the stock size.

Some recreational fishers deliver their catches to the sales organisations. In this working document it is assumed that this group is not included in the interview material and that these landings are already included in the reported catches from the commercial fisheries.

In the 2010 AFWG report, the Norwegian recreational quantity of coastal cod was estimated at **10,900 t for 2009**.

Tourist fisheries

There is one report available to indicate the level of tourist fisheries in Norway. The report is by a consultant company Essens management (Anon, 2005) and is based partly on Hallenstvedt and Wulff, 2004 and partly by surveys on the number of tourists who say they have been fishing in the sea.

Based on Hallenstvedt and Wulff (2004), the consultant company Essens management (Anon, 2005), and an assumption of an 10% increase per year from 2004 to 2009 in sea fishing tourism, the estimated quantity fished by tourists **in 2009 was 1,800 t cod**, all assumed to be coastal cod. This estimate is not so different from the scientific estimate of Vølstad et al. (2011) of **1,586 t of cod** fished by tourists north of 62N associated with registered tourist businesses/ companies in 2009 (27 t south of 62N). However, the total catch of coastal cod by tourists in 2009 north of 62N must have been higher due to the informal tourist fishing sector (eg private rental, camping etc). Hallenstvedt and Wulff (2000, table 10) estimate the informal sector to be larger than the formal business sector north of 62N (factor 1.13).

Numbers caught at age

Thus, a quantity of **12,700 t NCC was assumed to be taken by the tourist and recreational fishers in Norway in 2009. This quantity** has been extrapolated to the years before and after using the product of population numbers and the fraction of the people during recreational sea fisheries. It is assumed that the amount of cod is 50% throughout all the years.

From Hallenstvedt and Wulff (2004) it is seen that in the northern part of Norway almost no gill net fishing is included in the recreational fisheries. It was therefore reasonable to use the samples from long line and hand line to split the catches into age. This practice was followed until and including 2017. For recent years the total catch-in-numbers-at-age in the commercial landings have simply been upscaled with the added amount of recreational catches in tonnes assuming that the age distribution of the catches in the two fisheries are the same.

2. New project and revised results since 2010

A new project was conducted in the period 2017-2020 by IMR in collaboration with several Norwegian institutions (NINA, Akvaplan-niva, NMBU and Nordland Research), and a number of international partners. The main goal of the project has been to develop cost-effective methods to map catches and socio-economic dimensions of marine recreational fisheries (MRF) in Norway. The project tested the most commonly accepted methods for mapping recreational fishing in use internationally, such as telephone interviews, digital questionnaires, catch diaries on paper and web, and interviews of recreational fishermen in the field (on land and by boat). Three study areas Troms, Hordaland, and Oslofjord, were chosen because they represent contrasts in recreational fishing (Figure 1). The project is currently being finished and reports will follow, and for the purpose of WKBARFAR we here present some preliminary and relevant results.

The catches of tourist fishermen and locals who fished with hand-held gear from a boat were dominated by cod and saithe in northern Norway, while mackerel and saithe dominate in southern Norway. A big share of the catch taken by anglers is released again, but this varies with species. Based on investigations in other countries we anticipate a mortality rate of 100% of fish caught by rod from land, and 20% of released cod caught by rod and handline at sea (e.g., Weltersbach and Strehlow 2013; Capizzano et al. 2016).

The regional surveys show that fishing tourists account for less than half of the catches from the total recreational fishing with rod and line from boats in Troms (Table 2). Calculations show permanent residents and fishing tourists who fish with rod or handline from a boat can account for landings of more than 2000 tonnes of cod in Troms alone. In addition, comes catches by residents using fixed gears such as pots, longline, and gillnets which this project don't estimate. A total of 252 tons cod was delivered by resident recreational fishermen to industry facilities in Troms in 2019, but most of the resident catches are used in own households. See Table 1 for total landed cod by resident recreational fishermen at industry facilities north of 67N, and between 62-67N. These landings are already included in the official Norwegian landings statistics.

Norwegian residents' catches for own household

Ferter et al. 2021 show that permanent residents and fishing tourists who fish with rod and line from boat may account for landings of around 2160 tonnes of cod in Troms county, or 2.55 times the tourist fishing alone (Table 2). In addition comes catches for own household taken by fixed gear such as pots, fyke nets, longline, and gillnets, which are probably significant. The recreational fishery by residents in Troms fishing with rod and line from boat hence caught 2160 tonnes minus 848 tonnes (caught by tourists) equals 1312 tonnes of cod in one year 2018-2019 (Ferter et al. 2021; Table 2).

Tourist fishing with rod and line

Historical there has been no reporting system for coastal cod (NCC) taken by recreational or tourist fishers in Norway. In 2019 the Norwegian Directorate for Fisheries established a web-portal for obligatory catch reportings (both kept and released fish) by all registered fishing camps. Not all companies did report, and in Table 4 the reported catch has been raised to all companies in the county (Table 3) and finally summed for all counties in the region. Table 1 shows that the tourist fishing effort has about doubled from 2009 to 2019. The total quantity of cod caught by tourists staying in tourist businesses has also more than doubled from 1586 tonnes in 2009 (Vølstad et al. 2011) to about 3455 tonnes in 2019 (Table 4).

3. Preliminary input to the cod assessments north of 62˚N

Cod types

Based on the seasonality of the tourist fishing (Figure 2) it is assumed that most of the the cod catches are coastal cod. Ferter et al. 2021 report though that there is a move towards more tourist fishing also in winter and this will eventually lead to more northeast-arctic cod in the catches. The catches by Norwegian residents are believed to contain more northeast-arctic cod as much of this fishing is happening in the winter spawning season.

Current preliminary catch estimation

If we assume that the ratio between tourist fishing and residents fishing with rod and line is the same in all counties north of 62N, i.e., total recreational rod and line fishery is equal to 2.55 times the tourist rod and line fishery (Table 2), then the total recreational fishery using rod and line from boat catch is about 5520 tonnes of cod north of 67N and 3300 tonnes of cod between 62-67N (Table 4). In addition comes the catches taken by tourists outside the tourist businesses (private lodging, camping tourists) and catches for own household taken by residents using fixed gears such as pots, fyke nets, longline, and gillnets which we unfortunately don't have quantified. In order to quantify the total recreational fishery, the landed and sold cod by resident fishers in recent years of about 1600 tonnes and 340 tonnes, north of 67N and between 62-67N, respectively, should also be added (Table 1).

A quantity of 12700 tonnes Norwegian coastal cod has by the ICES AFWG been assumed to be taken by the tourist and recreational fishers in Norway annually since 2009. The current documented estimate of about 9000 tonnes is clearly an underestimate (because of tourists outside registered tourist businesses and residents fishing with fixed gears are not included). Until a better quantification of these missing recreational segments, **the authors propose to keep the quantity of 12700 tonnes recreational catch of Norwegian coastal cod on top of the commercial reported landings, with 7900 tonnes north of 67N and 4800 tonnes between 62-67N. It is necessary to update the recreational catch with a better estimate as soon as this is available.**

Length and age distribution of the recreational catches

A total of 698 cod were length measured from about 40 tourist catches in Troms in 2018-2019 (Table 5). Likewise, 138 cod were length measured from about 15 resident catches by rod and line (Table 5). Length-weight parameters were calculated from the Institute of Marine Research's database of length measurements and individual weights of fish (Berg and Nedreaas 2021) using the w (kg)=0.0000050 x L(cm)^3.090. Until a better recreational catch sampling is in place, it is suggested to use the annual age-length keys for coastal cod from the annual trawl-acoustic survey in October to convert catch-in-numbers-at length to numbers-at-age (Table 6). However, for the current data revision the total catch-in-numbers-at-age in the commercial landings have simply been upscaled with the added amount of recreational catches in tonnes for the whole time series 1994-2019 (Tables 7 and 8).

4. Summary

Tourists in tourist businesses	✓	incl. lengths 2018-2019
Tourist outside tourist businesses (camping, private lodging)	?	
Residents fishing with rod and line	✓	incl. few lengths 2018-2019
Residents fishing with fixed gears (gillnets, longline, traps etc)	?	

5. References

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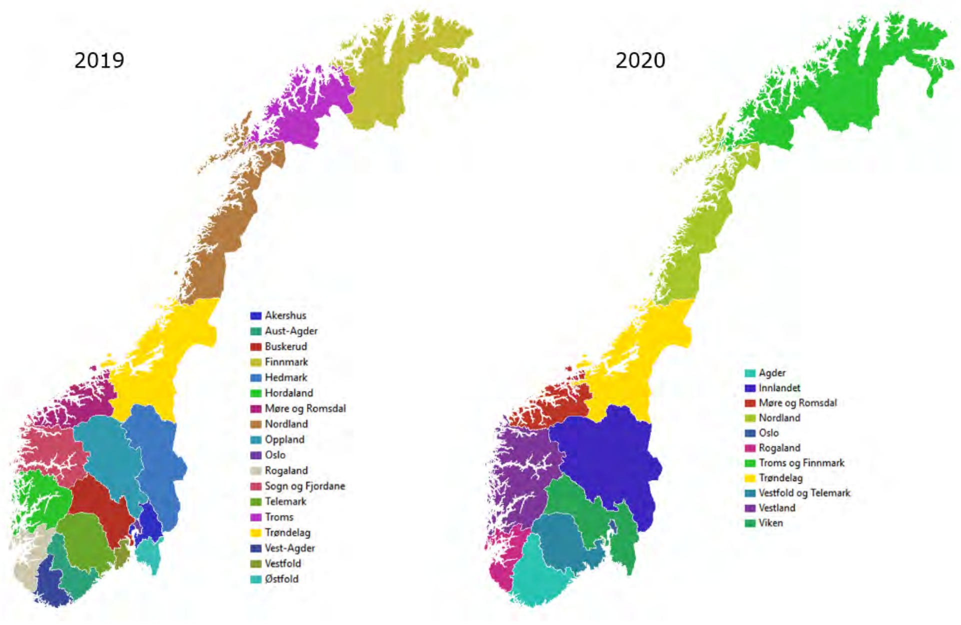

Figure 1. Norwegian counties before and after 2020. Source: trondelagfylke.no

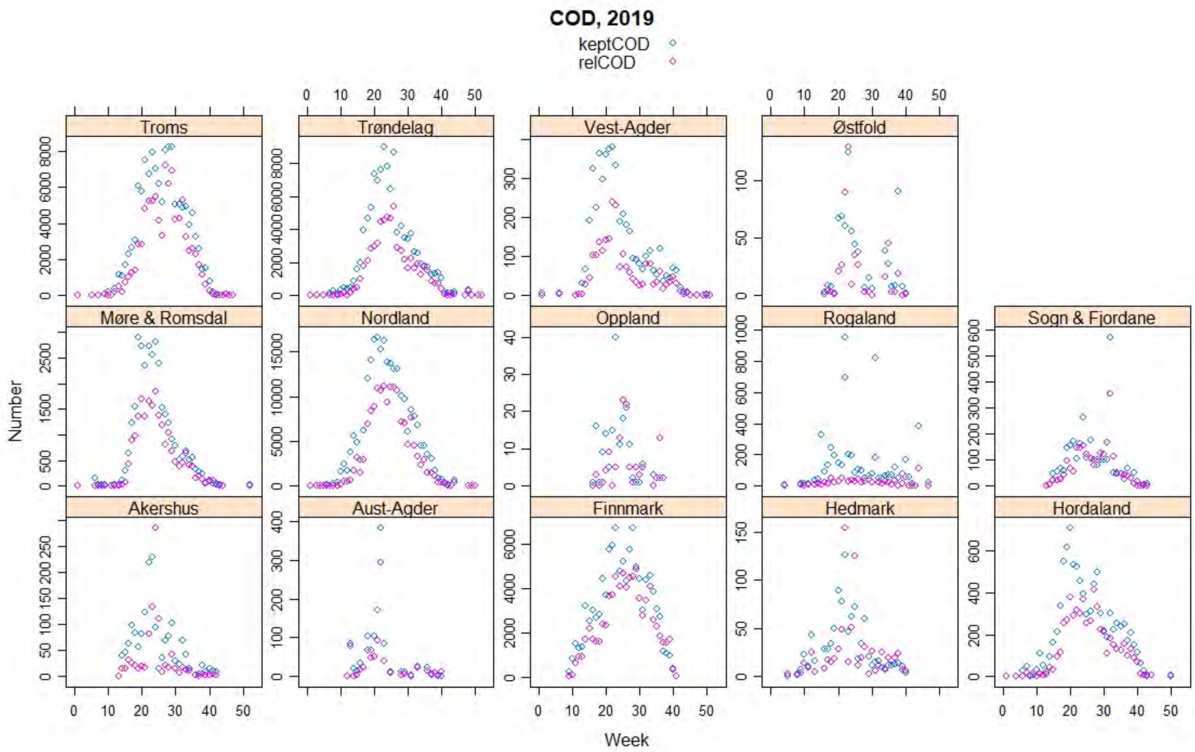

Figure 2. Monthly account of the reported catches of cod by tourist companies (self-reporting) to the Norwegian Directorate of Fisheries in 2019 per county, both kept and released cod, respectively. The main fishing period is during week no. 10-40 (March-September). The companies have reported using their company office address, and this explains why inland counties as Hedmark and Oppland are on the list.

Table 1. Reported landed and sold cod by Norwegian recreational fishers 2012-2019 (in tonnes). These landings are included in the official Norwegian landings statistics, and hence considered as a commercial catch and not included in the additional recreational cap.

Year/Area	North of 67˚N	Between 62-67˚N	Total
2012	1 425	239	1 665
2013	450	167	617
2014	774	229	1 003
2015	618	226	844
2016	810	332	1 142
2017	772	307	1 078
2018	1 206	340	1 546
2019	1 603	339	1 943
2020	1 785	347	2 132

Source: Norwegian Directorate of Fisheries

Table 2. Estimated annual catch of cod by (A) marine angling tourist staying in registered tourist fishing businesses in Troms based on the tourist fishing survey in 2018 and 2019, and (B) marine recreational anglers (resident and tourist anglers combined) in Troms based on the roving creel survey between April 2018 and March 2019.

A

	Troms					
	Kept				Released	
	Numbers		Biomass		Numbers	
	N	RSE (%)	Tonn	RSE (%)	N	RSE (%)
Cod	365549	6	848	9	175505	7

B

	Kept				Released	
	Numbers		Biomass		Numbers	
	N	RSE (%)	Tonn	RSE (%)	N	RSE (%)
Cod	930949	44	2160	44	236582	40

Table 3. Effort (# companies and boats) in tourist fishing in Norway. An account of all companies defined as tourist fishing companies in 2009 and 2019, and the number of boats they were renting out. The figures from 2009 are from Vølstad et al. (2011) and the 2019 companies/boat figures are official statistics from the Directorate of Fisheries.

County	**2009**		**Feb 2020**		**Retained Cod (in tons)**			
	Companies	**Boats**	**Companies**	**Boats**	**2009**	**RSE%**	**2019***	**RSE%**
Finnmark	28	74	67	368				
Troms*	52	267	110	510	209	26	848	9
Nordland	123	570	164**	842**				
Trøndelag	91	576	185	1197				
Møre & Romsdal	64	257	174	750				
SUM north of 62N	358	1744	700	3667	1586			
Sogn & Fjordane	21	76	75	274				
Hordaland*	30	196	161	610	7	19	31	12
Rogaland	17	112	58	248				
Vest-Agder	8	185	28	75				
Aust-Agder	5	70	1	0				
Telemark	3	6	0	0				
Vestfold	1	2	0	0				
Akershus	2	2	4	15				
Oslo*	0	0	2	2				
Østfold	0	0	3	2				
SUM south of 62N	87	649	332	1226	27			
SUM all over	445	2393	1032	4893				

**IMR investigations in 2019. RSE% is percentage relative standard error of the point estimate.*
*** Hereof 55 companies (34%) and 260 boats (31%) south of 67N*

Table 4. Official reportings to the Norwegian Directorate of Fisheries from tourist fishing companies and raised to all companies in the county.

County	Kept cod (in numbers)	RSE (%)	Released cod (in numbers)	RSE (%)	Total dead cod (in numbers)[1)]	Total dead cod (tons in round weight)[2)]
Finnmark	229962	3	187892	5	267540	564
Troms	311119	3	227169	4	356553	751
Nordland	508269[3)]	2	340158[3)]	3	576301[3)]	1214[3)]
Trøndelag	315004	2	179613	3	350927	739
Møre and Romsdal	80738	3	39695	4	88677	187
TOTAL	**1445092**	**1**	**974527**	**2**	**1639997**	**3455**
Hereof north of 67N	896869		653171		1027503	2165
Hereof south of 67N	548223		321355		612494	1290

[1)]Assuming 20% mortality of post-released cod. [2)] using average weight of the cod caught in Troms, i.e. 2.107 kg. [3)] Hereof about 30% south of 67N

Table 5. Length distributions of tourist- and resident catches of cod by rod and line in Troms county in 2018-2019.

Length (cm)	Tourists	Residents
30-34	2	1
35-39	0	2
40-44	7	14
45-49	33	20
50-54	90	8
55-59	127	8
60-64	163	10
65-69	116	3
70-74	55	11
75-79	42	11
80-84	19	16
85-89	20	17
90-94	9	12
95-99	8	4
100-104	2	1
105-109	3	
110-114	0	
115-119	0	
120-124	1	
125-129	1	
Tot numbers	698	138
N samples	40	15
Average weight (kg)	2.11	2.79

Table 6. Coastal cod. Acoustic abundance indices (in thousands) by length and age in 2019. *Staby et al. 2020. Toktrapport/Havforskningsinstituttet/ISSN 15036294/Nr. 6–2020*

Lengde *Length (cm)*	Alder (Årsklasse) / *Age (Year class)* 1 (18)	2 (17)	3 (16)	4 (15)	5 (14)	6 (13)	7 (12)	8 (11)	9 (10)	10+ (09+)	Sum
5-10											0
10-14	4290	.	.	.	.	.	.	.	.	.	4290
15-19	1535	9	.	.	.	.	.	.	.	.	1544
20-24	1403	443	.	.	.	.	.	.	.	.	1846
25-29	288	789	19	.	.	.	.	.	.	.	1096
30-34	36	671	210	.	.	.	.	.	.	.	917
35-39	.	1058	609	126	4	.	.	.	.	.	1797
40-44	.	426	819	231	61	.	.	.	.	.	1537
45-49	.	56	1974	342	111	.	.	.	.	.	2483
50-54	.	.	1245	605	375	57	.	.	.	.	2282
55-59	.	19	589	980	530	118	43	43	4	.	2326
60-64	.	.	766	944	826	372	150	41	.	.	3099
65-69	.	.	132	394	1005	476	262	26	226	44	2565
70-74	.	.	.	455	692	458	410	172	66	28	2281
75-79	.	.	.	128	601	375	407	138	30	137	1816
80-84	.	.	.	11	195	334	233	158	44	67	1042
85-89	.	.	.	.	40	125	200	100	33	27	525
90-94	.	.	.	.	2	166	132	21	68	76	465
95-99	.	.	.	.	.	36	21	91	152	47	347
100+	.	.	.	.	.	3	180	85	185	126	579
Sum	7552	3470	6363	4216	4442	2520	2037	875	808	552	32836

Table 7. Total catch-in-numbers-at-age of coastal cod north of 67N incl. recreational catch.

NEW Coastal cod catch-in-numbers ('000)-at-age. Total north of 67N including recreational catch.											
AGE										**Tonnes**	**Hereof**
	2	3	4	5	6	7	8	9	10+	**fished**	**recreational**
1994	13	115	1148	5158	4414	3235	1313	356	793	61723	9144
1995	24	264	945	3183	5567	3672	2106	1094	711	66051	9144
1996	50	934	1720	2473	3805	3752	1471	659	709	50840	9020
1997	68	1326	2514	2334	2797	3248	2215	674	890	55624	9020
1998	523	1957	7718	5268	3341	1002	935	452	471	54544	9082
1999	97	1116	4152	6040	2492	957	644	482	520	47390	8646
2000	38	670	3201	4929	2812	1037	472	141	342	41541	8460
2001	13	442	2497	3006	2199	1288	409	140	661	32806	8335
2002	53	389	1959	3265	3019	1335	796	231	459	40648	8460
2003	156	454	1234	2408	2815	1562	754	399	326	37900	8646
2004	30	227	1352	1926	2774	1989	993	415	470	39533	8335
2005	17	307	1176	2525	2550	1862	911	324	440	38308	8211
2006	28	271	1556	2410	3193	2115	1240	490	482	44970	8087
2007	47	492	1567	2181	1737	1423	624	362	365	34287	8087
2008	81	498	1284	2458	1994	1294	741	358	369	35674	7962
2009	28	612	896	1582	1605	1091	563	579	284	30888	7900
2010	35	651	925	3474	2388	1295	647	347	1051	42704	7900
2011	83	597	1550	1690	1588	1386	728	440	747	35882	7900
2012	484	1317	1458	1447	1666	984	471	229	772	34678	7900
2013	179	689	1403	1421	1245	965	655	300	466	29276	7900
2014	119	680	1110	1695	1130	911	704	400	534	30650	7900
2015	407	1360	1734	1537	2089	1278	785	537	1072	42383	7900
2016	86	1086	2305	1835	1998	2458	1362	743	1244	57403	7900
2017	969	1806	2373	2661	2391	1707	1525	802	1035	62173	7900
2018	210	691	1800	2007	1873	1740	918	637	611	42432	7900
2019	60	1163	1585	2167	1934	1537	1202	387	633	43761	7900

Table 8. Total catch-in-numbers-at-age of coastal cod between 62-67N incl. recreational catch.

NEW Coastal cod catch-in-numbers ('000)-at-age. Total between 62- 67N incl. recreational catches.											
AGE	2	3	4	5	6	7	8	9	10+	Tonnes landed	Hereof recreational
1994	2	14	207	538	676	523	296	132	210	11937	4511
1995	4	51	341	647	797	757	433	184	155	14492	5477
1996	3	120	455	723	572	476	245	68	82	11687	4417
1997	5	253	369	456	407	399	283	95	72	10226	3865
1998	38	334	842	937	628	207	155	42	43	11718	4429
1999	5	226	610	600	497	240	103	128	51	10776	4073
2000	3	456	1311	773	299	107	96	32	69	10979	4149
2001	3	184	832	897	598	293	101	34	169	10315	3898
2002	15	153	627	711	768	240	91	22	28	12077	4565
2003	36	325	377	907	633	605	178	35	85	14159	5351
2004	9	194	581	451	695	403	242	60	45	11931	4509
2005	3	105	619	848	722	426	197	61	31	12994	4911
2006	16	76	484	968	888	282	156	84	79	13525	5112
2007	18	252	597	814	620	185	83	38	47	12609	4765
2008	46	153	1330	990	290	395	103	56	71	14727	5566
2009	1	375	1109	433	519	178	124	70	34	11945	4800
2010	7	187	651	706	398	423	81	58	74	12434	4800
2011	5	98	518	811	447	325	109	59	58	11928	4800
2012	45	179	425	795	502	442	115	57	58	12987	4800
2013	9	105	463	414	480	327	154	52	31	9931	4800
2014	1	100	293	690	469	400	140	76	68	11044	4800
2015	41	293	503	449	515	234	135	72	80	9804	4800
2016	2	151	448	566	371	360	218	120	150	10762	4800
2017	28	158	592	600	337	208	152	51	73	8959	4800
2018	19	118	272	620	532	293	187	75	66	9236	4800
2019	12	88	223	265	336	316	201	54	63	7765	4800

Working Document 16 to the ICES benchmark workshop on Barents Sea and Faroese stocks (WKBarFar), 1-5 February 2021

Status of the coastal cod (Gadus morhua) between 62˚N and 67˚N using a Length-Based Spawning Potential Ratio (LBSPR) approach

Authors: Yves Reecht[1], Kotaro Ono[1], Sofie Gundersen[1] and Kjell Nedreaas[1]

[1]Institute of Marine Research, PB-1870, N-5817 Bergen, Norway;

Last modified: 19. Mar. 2021

Keywords: *Gadus morhua*, life history traits, LBSPR,

1 Introduction

Coastal cod south of 67°N was formerly managed together with the coastal cod north of 67°N, and has now been proposed to be split as a separate management unit. The new management unit dealt with in this document covers the Norwegian statistical areas 6 and 7 (Fig. 1.1). This sub-population represent about 20% of the remaining commercial catches and is not as consistently covered by the main surveys relevant for monitoring cod. Former management was never based on a validated assessment model and current data availability and quality cannot support a full analytical assessment. It was therefore suggested to promote a data limited approach to support management of this stock.

In this document, we investigate the relevance of a length-based spawning potential ratio approach (LBSPR) for the management of coastal cod between 62° and 67°N.

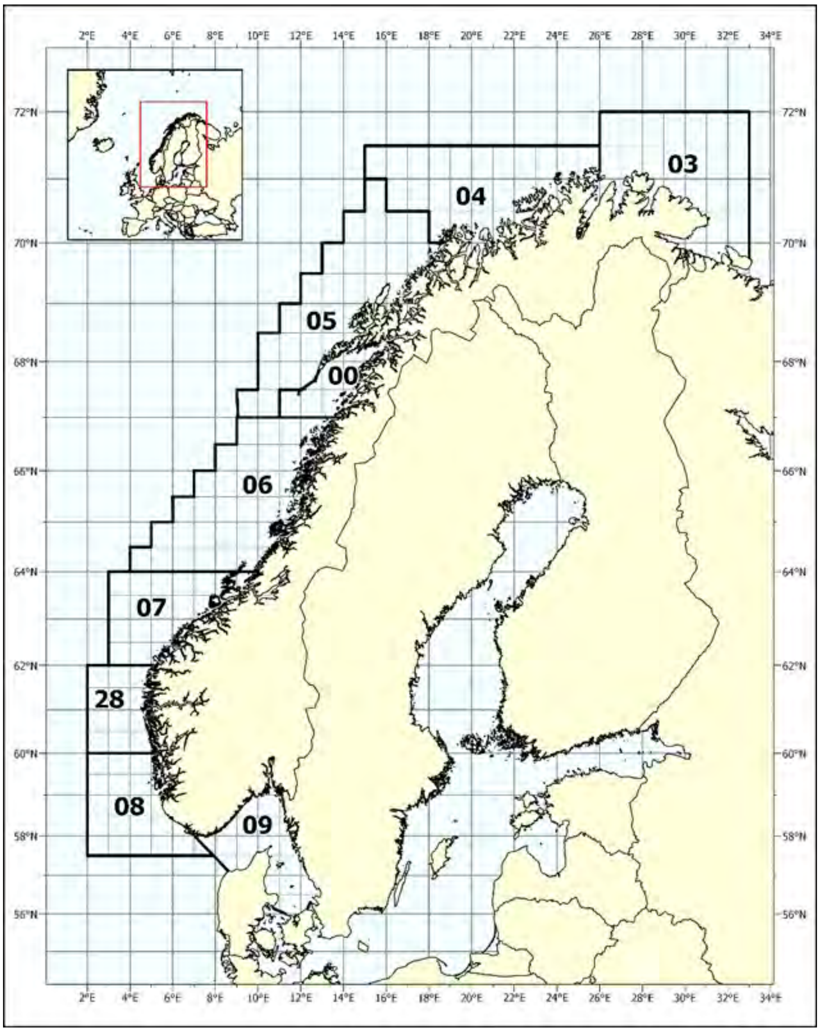

Figure 1.1. Map showing the Norwegian statistical coastal areas. Area 03 is part of ICES Subarea 1, Areas 04, 05, 00, 06 and 07 are part of ICES Subarea 2, Areas 28 and 08 are part of ICES Subarea 4, and Area 09 corresponds roughly with ICES Subarea 3.

2 Data availability and preparation

2.1 Length composition data

Two potential source of size composition information have been identified as the coastal survey data and the reference fleet data.

2.1.1 Coastal survey

Size composition within stations is randomly sampled. But because of the sampling of otoliths – further used to segregate coastal and NEA cod – is stratified by size, estimating the size distribution of coastal cod only would require an allocation of individuals to coastal or NEA cod stock based on the P(coastal | size class). Figure 2.1 however shows that the assumption can be safely made that all cod caught during this survey are coastal cod, without any substantial risk of generating a bias to the size distribution. This comes with some reserves for the smallest cods, presenting fewer otolith samples.

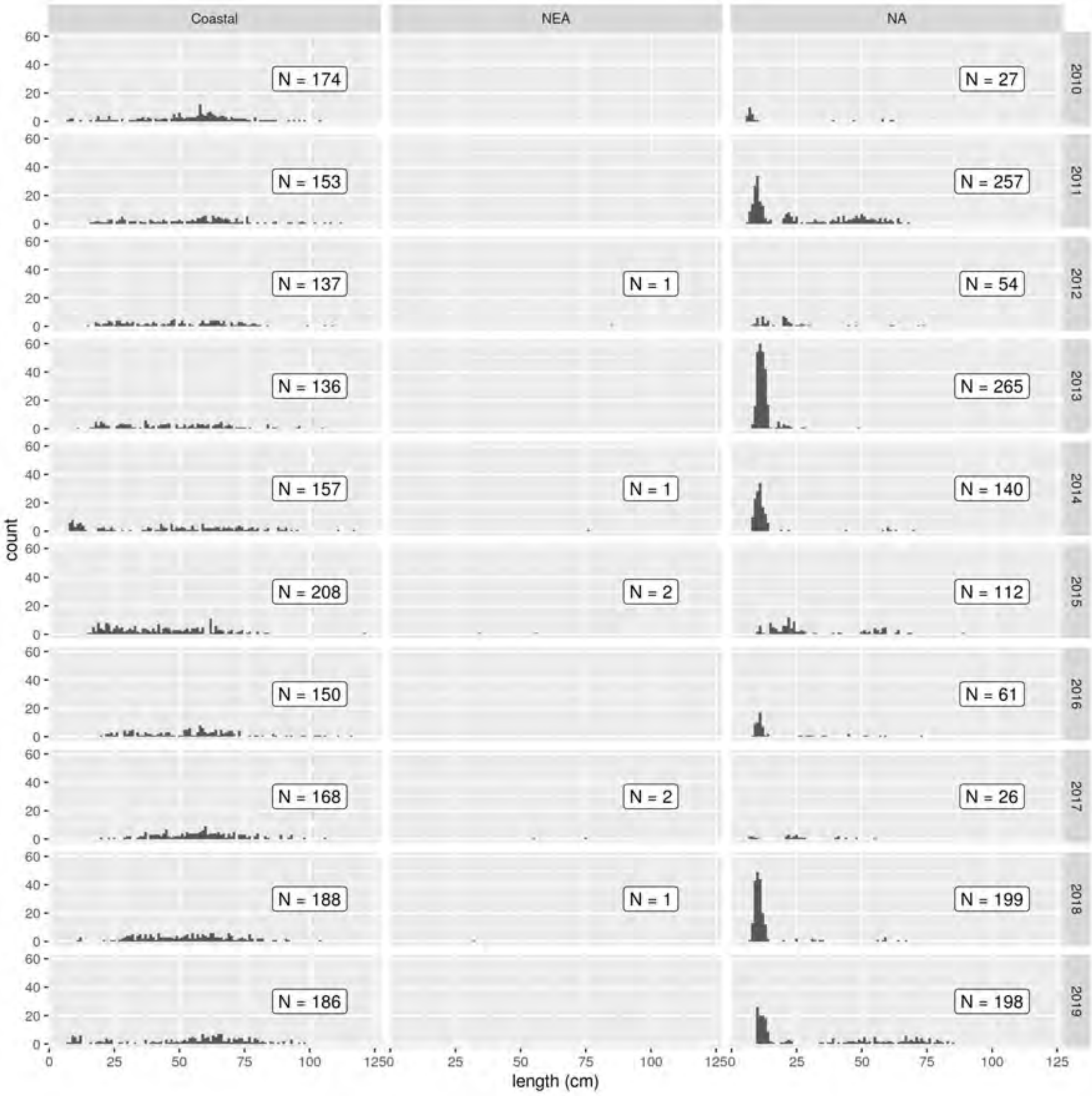

Figure 2.1. Length composition and sample size of coastal, NEA and unclassified cod per year, pooled for area 6 and 7. Estimated from the coastal survey (inshore and offshore components pooled).

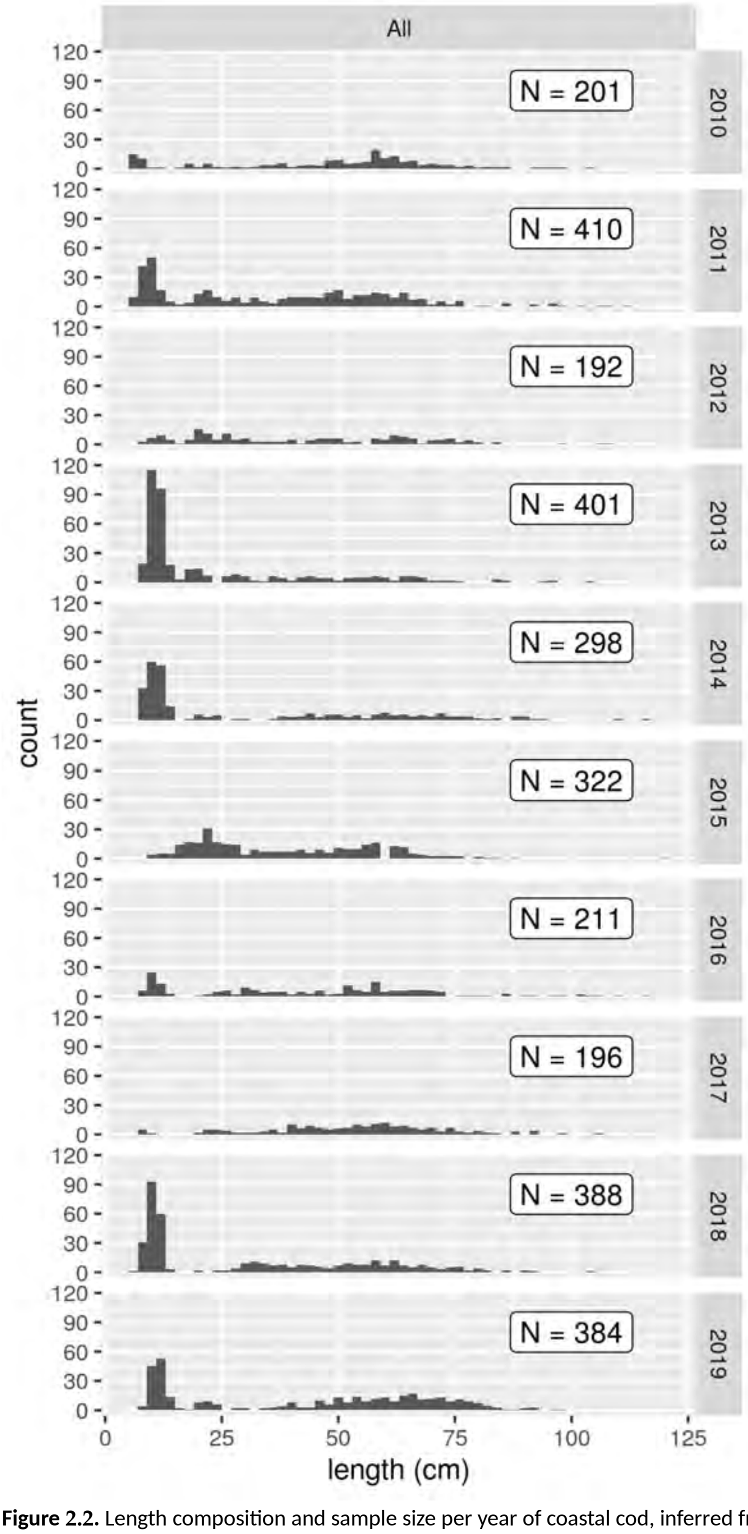

Figure 2.2. Length composition and sample size per year of coastal cod, inferred from the coastal survey data in area 6 and 7 (pooled).

Fig. 2.2 shows a summary of pooled size distributions per year based on the assumption that all (but the few identified as NEA) cod caught in the coastal survey belong to the coastal stock. Two issues emerge: first some distributions are multi-modal which does not sit well with fitting a LBSPR model (sign that the distribution is either representing a population which is not at equilibrium or not representative of the population). This is common when data include large juvenile cohorts, which is a deviation to equilibrium. These juvenile cohorts are by definition of little interest for a spawning potential ratio approach though, and one may choose to use a truncated size distribution for fitting the model. This option however worsen the second issue which has to do with the very low sample sizes, well below the recommended 1000 individuals to fit a LBSPR model (Hordyk *et al.*, 2015a).

On this ground, it has been chosen not to use this source of data.

2.1.2 Reference fleet sampling

The Norwegian Reference Fleet is a group of active fishing vessels tasked with providing information about catches (self-sampling) and general fishing activity to the Institute of Marine Research. The fleet consists of both high-seas and coastal vessels that cover most of Norwegian waters. The High-seas Reference Fleet began in 2000 and was expanded to include coastal vessels in 2005 (*e.g.* Clegg and Williams, 2020). The reference fleet provides us with length measurements and random samples of otoliths which are, among others, used to distinguish coastal from NEA cod. Cod was mostly caught and sampled using gillnets. The number of stations sampled is summarized in Table 2.1.

As individuals are sampled randomly for size measurement, and for otolith reading within the size sample, the distribution of of those individuals classified as coastal cod could in theory be used directly, provided that the sampling is homogeneous among gillnet types, mesh sizes, etc. However, even pooled over areas, the sample sizes by year are fairly low for that purpose (Fig. 2.3) as LBSPR works best with samples of about 1000 individuals or more (Hordyk *et al.*, 2015a).

Table 2.1. Summary of reference fleet sampling per year and area, as number of stations with length sample, weight of the length sample (necessary if estimation of number caught), otolith sample (for classification in coastal / NEA). Limited to GNS gears, exclusive of those used to target monkfish and undefined.

		N station area 6 with				N station area 7 with		
Year	**Total**	**length samp**	**sample wg**	**otoliths**	**Total**	**length samp**	**sample wg**	**otoliths**
2005					9	0	0	0
2006	100	1	1	1	201	2	1	2
2007	68	9	7	3	167	2	0	2
2008	78	1	1	1	157	2	1	2
2009	124	13	11	11	280	13	0	8
2010	202	26	24	16	256	68	3	32
2011	117	15	12	8	222	101	23	43
2012	99	15	15	5	253	82	10	38
2013	148	23	19	9	406	117	45	66
2014	112	18	4	7	368	87	64	62
2015	75	16	3	3	337	129	61	58
2016	64	10	2	2	212	86	35	32
2017	64	18	4	4	171	107	40	26
2018	108	28	17	5	176	93	20	18
2019	109	24	6	11	133	122	5	36
2020	110	29	1	5	62	12	2	2

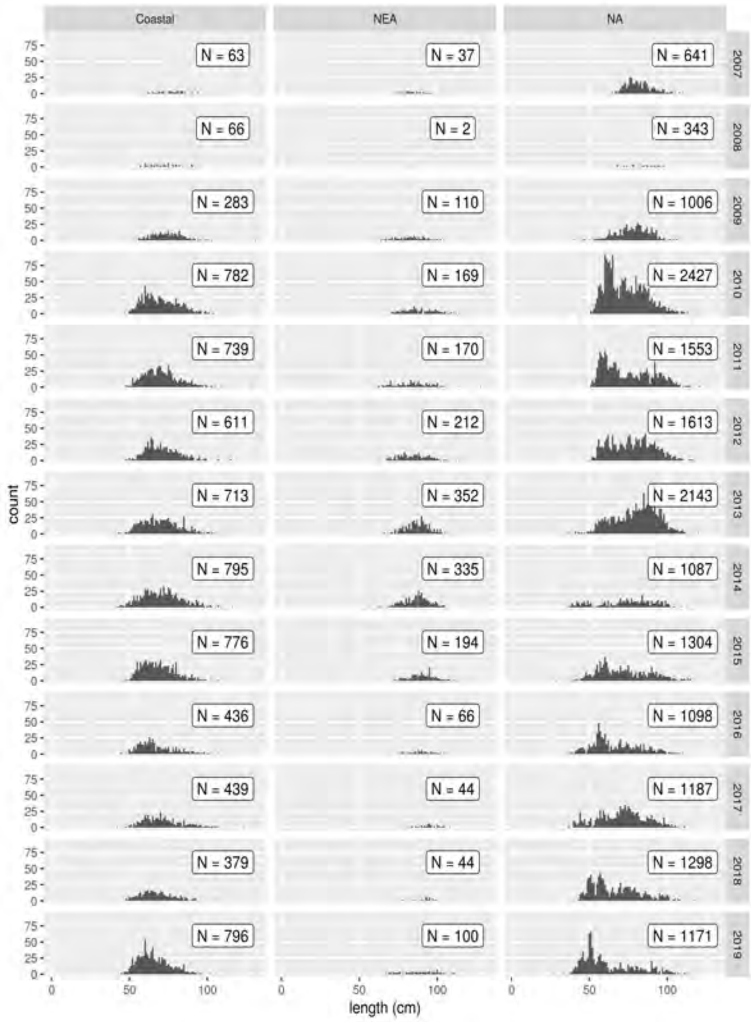

Figure 2.3. Length composition and sample size of coastal, NEA and unclassified cod per year, pooled for area 6 and 7. Samples from gillnets, except those used to target monkfish and undefined.

Moreover, investigation of the size distributions of individuals sampled for otoliths reveals discrepancies with the full size sample (Fig. 2.4) in some years. This is further confirmed by Q-Qplots comparing the empirical distributions of individuals sampled for otoliths and not sampled for otoliths (stock not identified) (Fig. 2.5). In cases where the size distribution of classified individuals is representative of the total size sample, the points are expected to follow closely the one-to-one line. Instead, some years show signs of unmatching tails (*e.g.* 2014, 2019) or displaced modes (*e.g.* 2011, "S" shaped pattern), which all together indicate cases of under-sampling of small individuals for otoliths. In this context, a scaling up the size composition of coastal cod to the whole size sample appears necessary.

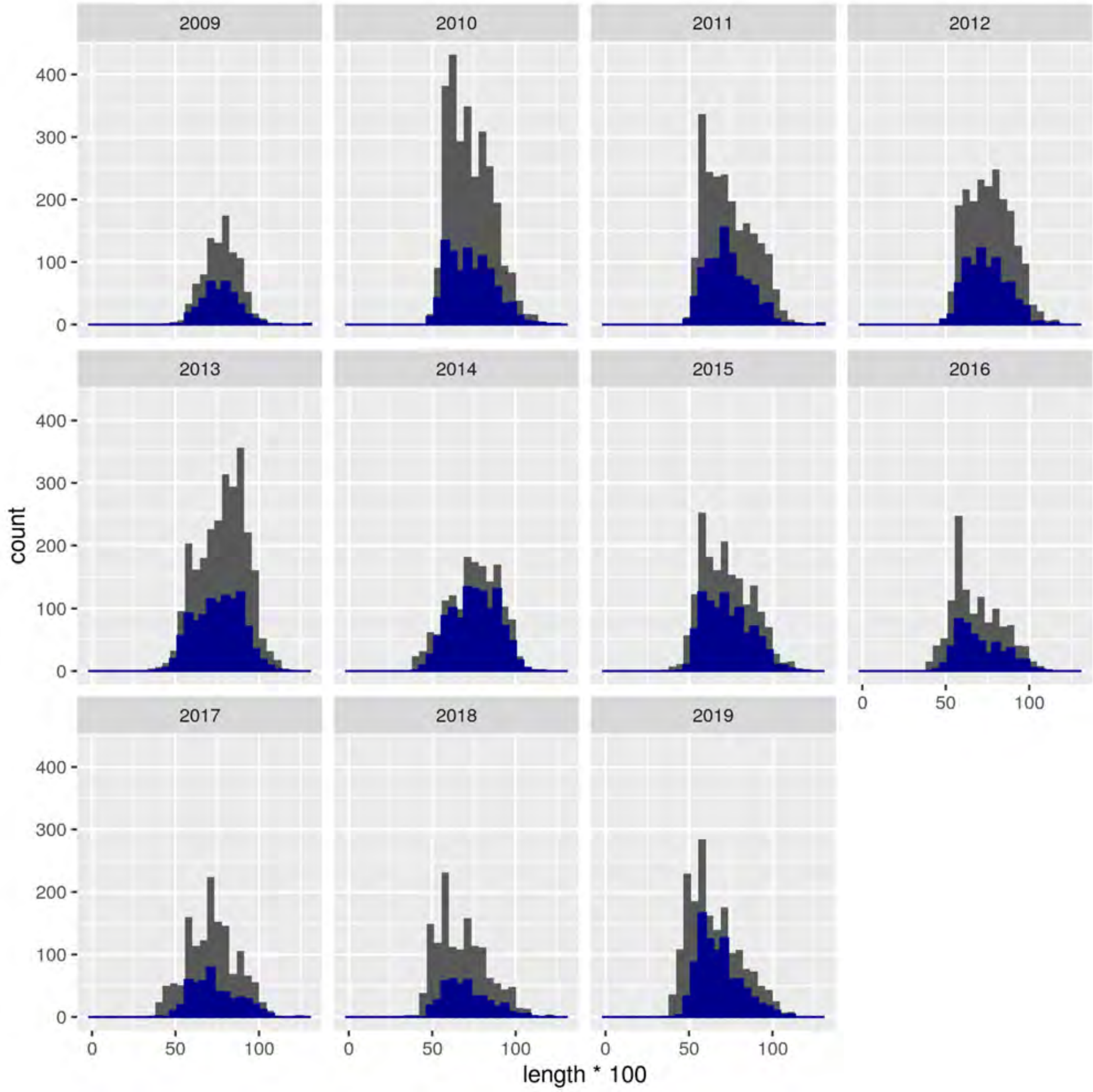

Figure 2.4. Size composition of pooled size samples of cod in area 6 and 7. In blue is the segment classified for stock (coastal and NEA pooled) based on otolith sampling. Gillnet (at the exclusion of those targetting monkfish and undefined) data from the reference fleet, pooled for areas 6 and 7.

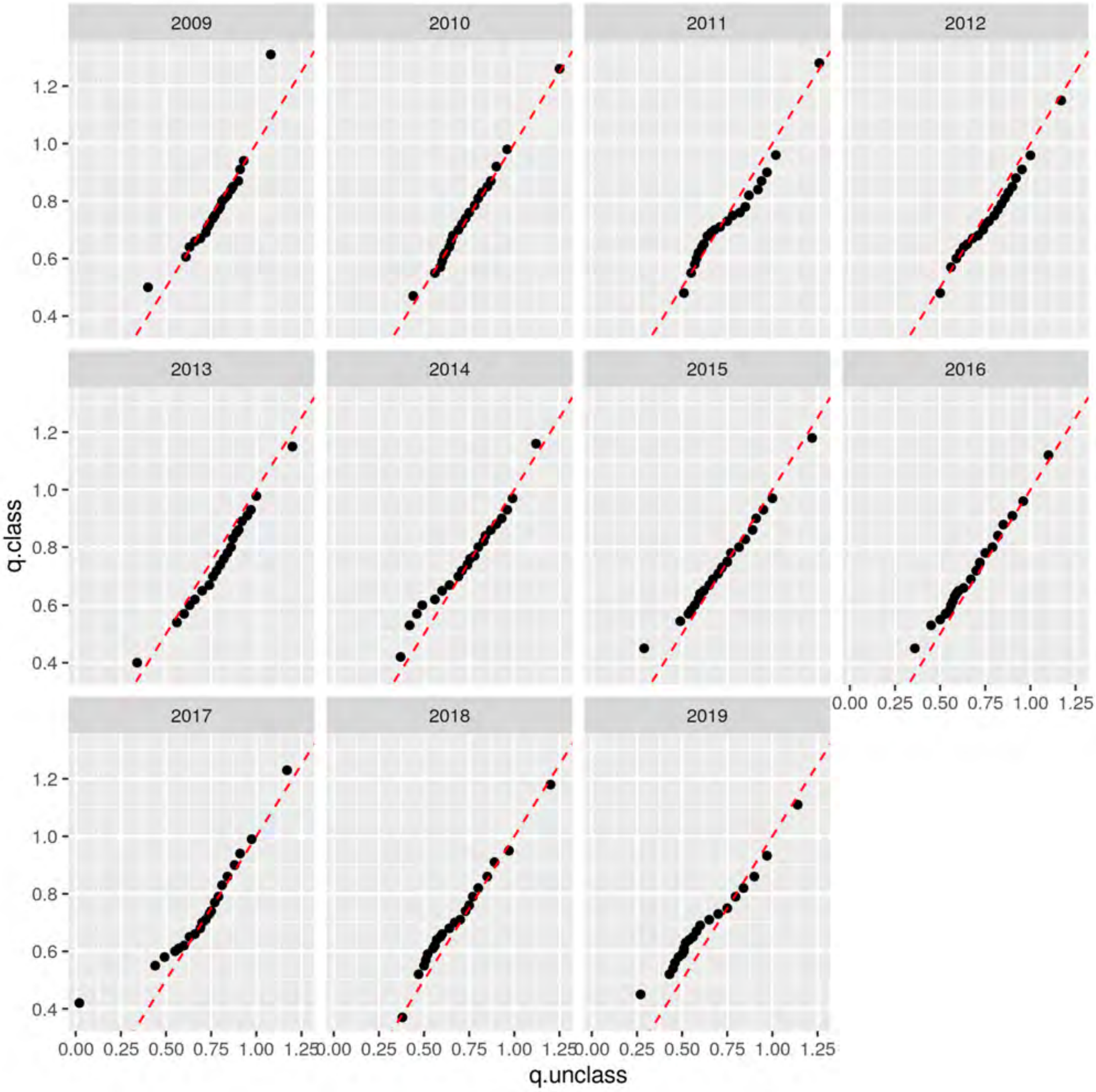

Figure 2.5. Empirical Q-Qplots per year for comparison of the distribution of individuals classified for stock (Y-axis, coastal and NEA pooled; blue bars in Fig. 2.4) vs. unclassified individuals (X-axis; grey bars in Fig. 2.4). Based on gillnet (at the exclusion of those targetting monkfish and undefined) data from the reference fleet, pooled for areas 6 and 7.

3 Methods and results

The length-based spawning potential ratio (LBSPR; Hordyk *et al.*, 2015a, 2016) was developed to help the management of data-poor fisheries based on a well-documented theoretical background (Hordyk *et al.*, 2015b; Prince *et al.*, 2015). It depicts the hypothetical size distribution of the commercial catches, under given exploitation levels, of a population at equilibrium based on the knowledge of its life history.

Based on a limited set of life history traits and ratios, the model can estimate the level of depletion likely to result in the observed size distribution in catches, and derive quantities linked to the exploitation pattern (selectivity ogive) and intensity. In particular, the model estimates F/M, the ratio of fishing to natural mortality, and the spawning potential ratio (SPR) representing the ratio of exploited over virgin spawning biomass from a per recruit perspective. Additionally, if information on the stock-recruitment relationship steepness is available, MSY reference points such as F_{MSY}/M or SPR_{MSY} can be derived (Brooks *et al.*, 2010; Hordyk *et al.*, 2015a).

The model is equilibrium based (constant recruitment and mortality at size – including fishing mortality) and assumed that (*i*) the length composition data in the catch is representative of the population size distribution and (*ii*) that the selectivity is asymptotic following a logistic function. As for the parametrisation, it does not require knowledge of the natural mortality rate (M), but instead uses the ratio of natural mortality and the Von Bertalanffy growth coefficient (k) (M/k), which is believed to vary less across stocks and species than M (Prince *et al.*, 2015). Other important input parameters are the asymptotic length, L_∞, and – for the estimation of the SPR – the maturity ogive ($Lm_{50\%}$, $Lm_{95\%}$). The model takes into account the effect of inter-individual variability in growth through a coefficient of variation of L_∞, but this is often arbitrarily fixed due to lack of information (Díaz *et al.*, 2016; Hordyk *et al.*, 2016).

Given the uncertainty in parameters and the demonstrated sensitivity of the model to input parameters (Hordyk *et al.*, 2015a, 2015b), we implemented a stochastic LBSPR approach similar on the principle to the one developed for Monkfish within the Arctic fisheries working group (ICES, 2020). Differences with this former approach include variations in the parametrisation of random inputs, and the inclusion, in our model, of bootstrapped size distributions to account for uncertainty in the observation of length compositions.

3.1 Raising coastal cod size distributions to the size sample

The individuals not sampled for otolith, and therefore not attributed to a stock, were randomly split among coastal and NEA cod based on a model of P(coastal) derived from the one developed for the CPUE index calculation (WD 17 and main report section 4.2.1). The model used here was improved substantially by including an additional smoother on size (Δ_{AIC} = -3448), and additional model selection was carried out to check that no other more parsimonious model was performing better. Diagnostics were checked following a similar approach as model without size effect (WD 17). The GAM model retained was:

```
gam(is_coastal ~ factor(area) * factor(year) + s(length) +
                 factor(quarter) + factor(gear),
    family=binomial(link = "logit"),...)
```

and was fitted using the R package mgcv. A representation of the model output, limited to areas 6 and 7 is presented in Fig. 3.1. It highlights that the probability, of an individual caught in this areas, to be a coastal cod increases in the course of the year and decreases with individual size. The very wide uncertainty in area 6 in 2008 reflects a scarcity of data and has no practical consequences as only data from 2010 onwards are used in the subsequent size-based approach.

Unclassified individuals sharing the same area, gear, year, quarter and size class were accordingly randomly split between coastal and NEA cod using a binomial random generator (see section 3.3).

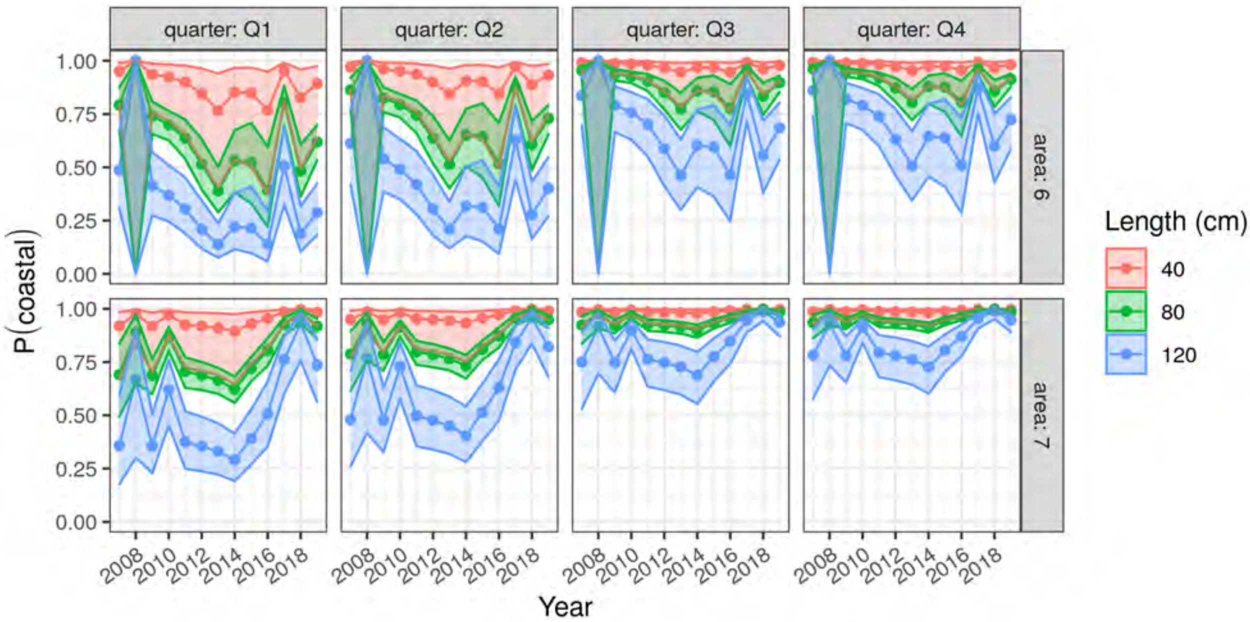

Figure 3.1. Predicted proportions of coastal cod at different sizes in the coastal reference fleet catches by statistical area and quarter during 2007-2019 based on otolith classification using all otolith categories (i.e., including uncertain classifications). The shaded polygon is the 95% confidence interval for the prediction.

3.2 Life history traits estimation

3.2.1 Prerequisites: selectivity estimates and sensitivity

Selectivity estimates were estimated using LBSPR with parameter borrowed from the northern sub-population, that were necessary for the ensuing parameter estimation procedure. Which estimated parameter were later used as input to a LBSPR model. In an effort to ensure that this circularity was not going to cause major issues and make sure that an iterative process could be avoided, the sensitivity of the selectivity parameter estimates to the misspecification of input parameters in LBSPR was first investigated. Values for the parameters L_∞ and M/k were altered in a ±15% range of their nominal value (L_∞ = 96.8 cm, M/k = 1.67 based on M following Then et al., 2015) and Mpow (size varying M exponent, nominal value assumed at zero, *i.e.* constant M) shifted between 0 and 1.2, which represent a fairly wide range of values.

Both L_{50} and L_{95} selectivity parameters were rather little sensitive to input parameters, except in the years 2013 and 2017 (Fig. 3.2). They were more sensitive to L_∞, which is also the most certain parameter. Sensitivity to both M/k and Mpow was low, although more pronounced for the two afore-mentioned years. Based on this results (and on later fits using different M estimates, see section 3.2.4), no cause for concern was found and the selectivity estimates based on parameter values borrowed from the northern sub-population deemed reasonable for growth parameter estimates in the southern sub-population.

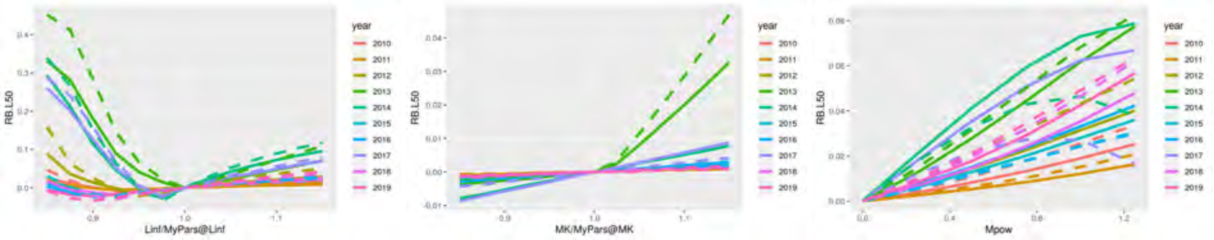

Figure 3.2. Sensitivity of the selectivity parameter L_{50} (solid lines) and L_{95} (dashed lines) to variations of LBSPR input parameters L_∞ (left panel; ±15% range to the nominal value), M/k (middle panel; ±15% range) and Mpow (right panel; 0 – the nominal value – to 1.2). Nominal values are borrowed from the northern coastal cod sub-population.

3.2.2 Growth parameters L_∞, k and CV(L_∞)

Two distinct size selective processes were involved in the sampling of aged individuals:

1. commercial fishing using gillnets typically retains individuals over 50cm.
2. among the individuals sampled for size measurement, we demonstrate in a previous section that sampling for age reading is slightly biased towards larger individuals in some years.

Size selective sampling of age data is a well documented source of bias in the estimation of growth parameters (*e.g.* Taylor *et al.*, 2005; Troynikov and Koopman, 2009; Gwinn *et al.*, 2010; Perreault *et al.*, 2019; Hilling *et al.*, 2020). There is a wealth of methods to include size selective sampling in the formulation of the likelihood while estimating growth parameters. Here, it was chosen, based on the trade off between implementation time and coverage of the various sources of bias, to use a composite weighted approach that cover both above mentioned size selective processes:

w = cw * saw

where the calibrated weights (CW) compensate for the size biased age sampling within the catch. They were calculated following (Perreault *et al.*, 2019). The SAW are weights correcting for size selectivity at age in the catch (loosely based on model 1 in Taylor *et al.*, 2005), using selectivity parameters estimated using LBSPR and parameters borrowed from coastal cod North of 67°N (section 3.2.1).

Parameters were estimated using two alternative models, differing only in how the age was coded: one using integer age (age_y) and the other based on decimal age, estimated based on the sampling month as $age_{dec} = age_y + month/12$. Both models presented a residual pattern (top left corner of respectively Fig. 3.3 and 3.4) consistent with what is expected while correcting for size-specific sampling biases (Perreault *et al.*, 2019). The model based on decimal age presented an additional seasonal residual trend (Fig. 3.4) which may be the result of unbalanced sampling of youngest ages throughout the year. This last model was retained based on (*i*) similarity of the asymptotic length with the one estimated for the northern sub-population while not grounds for expecting differences were known and (*ii*) consistency of the higher estimated growth coefficient k with reported faster growth of coastal cod at lower latitudes (Berg and Albert, 2003).

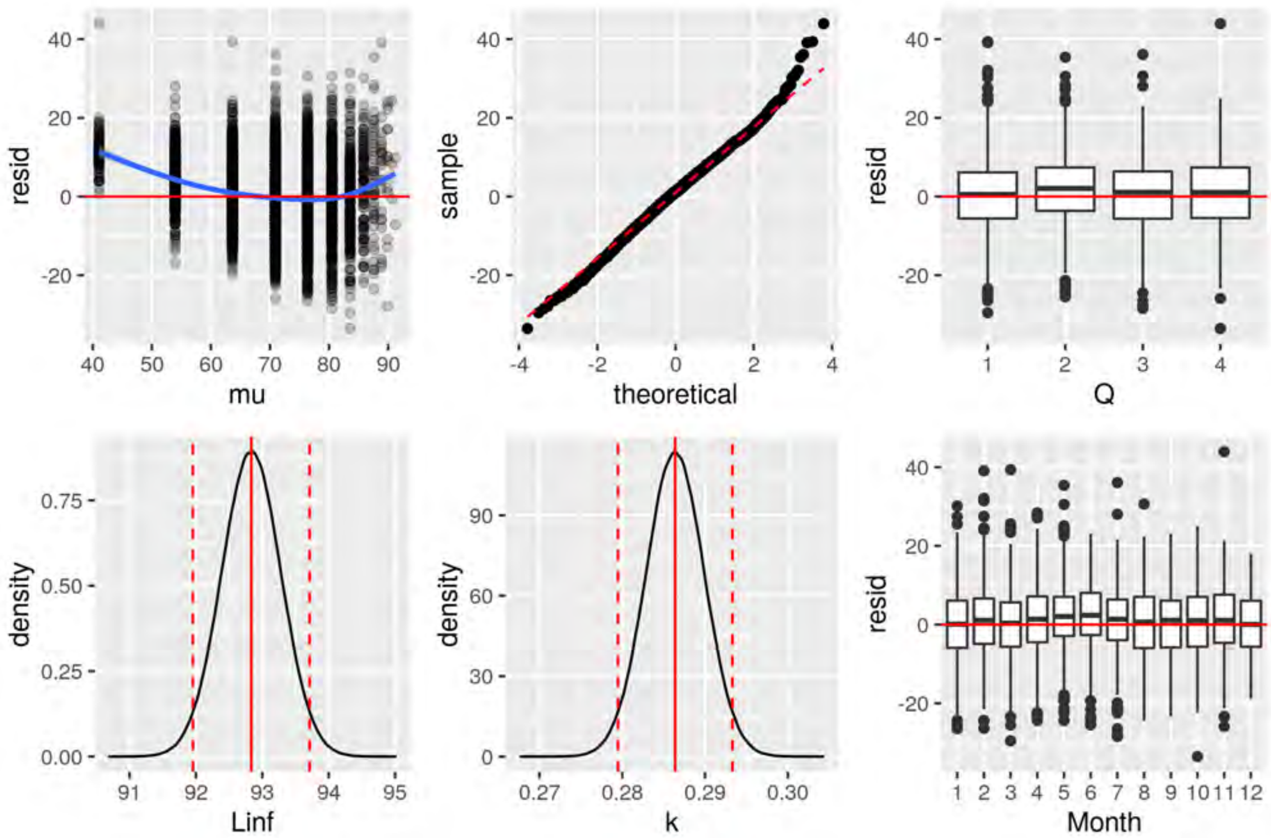

Figure 3.3. Von Bertalanffy growth function fitting (non-linear least squares) diagnostics and parameter (L_∞, k) distributions estimated for coastal cod south of 67°N, based on integer age . The residual pattern observed in the top-left panel is consistent with expectations following correction for size-selective sampling bias.

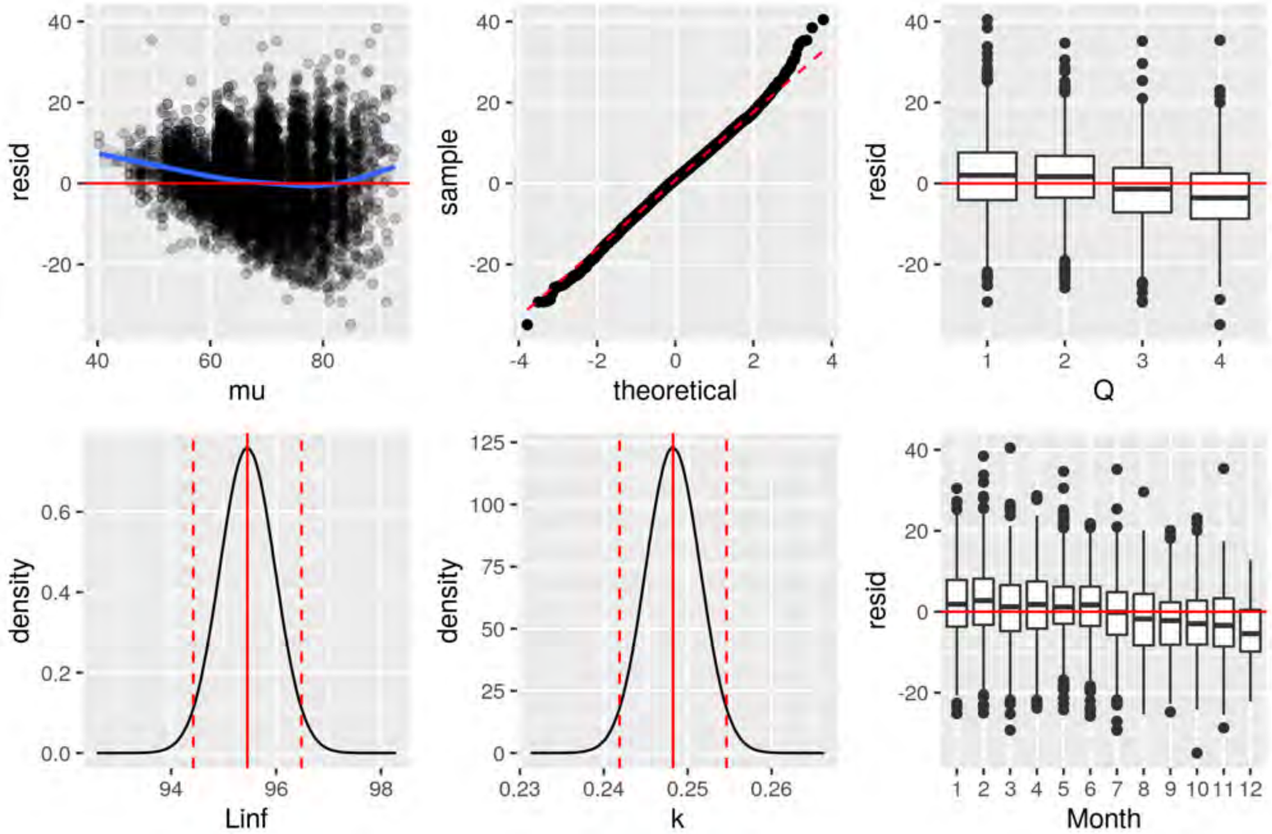

Figure 3.4. Von Bertalanffy growth function fitting (non-linear least squares) diagnostics and parameter (L_∞, k) distributions estimated for coastal cod south of 67°N, based on decimal age . The residual pattern observed in the top-left panel is consistent with expectations following correction for size-selective sampling bias.

3.2.3 Maturity

Maturity was estimated for the whole autumn coastal survey data north of 62°N, on account of scarcity of biological cod samples for the area between 62 and 67°N alone. For consistency with the choices made for the northern stock (WD26 and main report section 3.3.3), resting individuals (stage 4) where included in the mature fraction. The maturity parameters (length at 50% and 95% maturity) were estimated by fitting a binomial GLM on yearly bootstrapped maturity data with covariate length (500 resampled data sets). The model, in R notation is:

```
glm(is_mature ~ length,
    family=binomial(link = "logit"),...)
```

The parameters $Lm_{50\%}$ and $Lm_{95\%}$ were estimated for each year in each resampled dataset by rearranging the model equation $\log(p/(1-p))=\beta_0+\beta_1 \cdot length$ and replacing the values p=0.5 and p=0.95 respectively:

$$Lm_p=\frac{\log\left(\frac{p}{1-p}\right)-\beta_0}{\beta_1}$$

The yearly (2010-2019) parameter distributions are shown in Fig. 3.5 and do not exhibit any noticeable trend over time. For the later parametrisation of the stochastic LBSPR model, pairs of Lm_{50} and Lm_{95} parameters estimated from the same bootstrapped data set and year were drawn together to preserve the correlation between the two parameters.

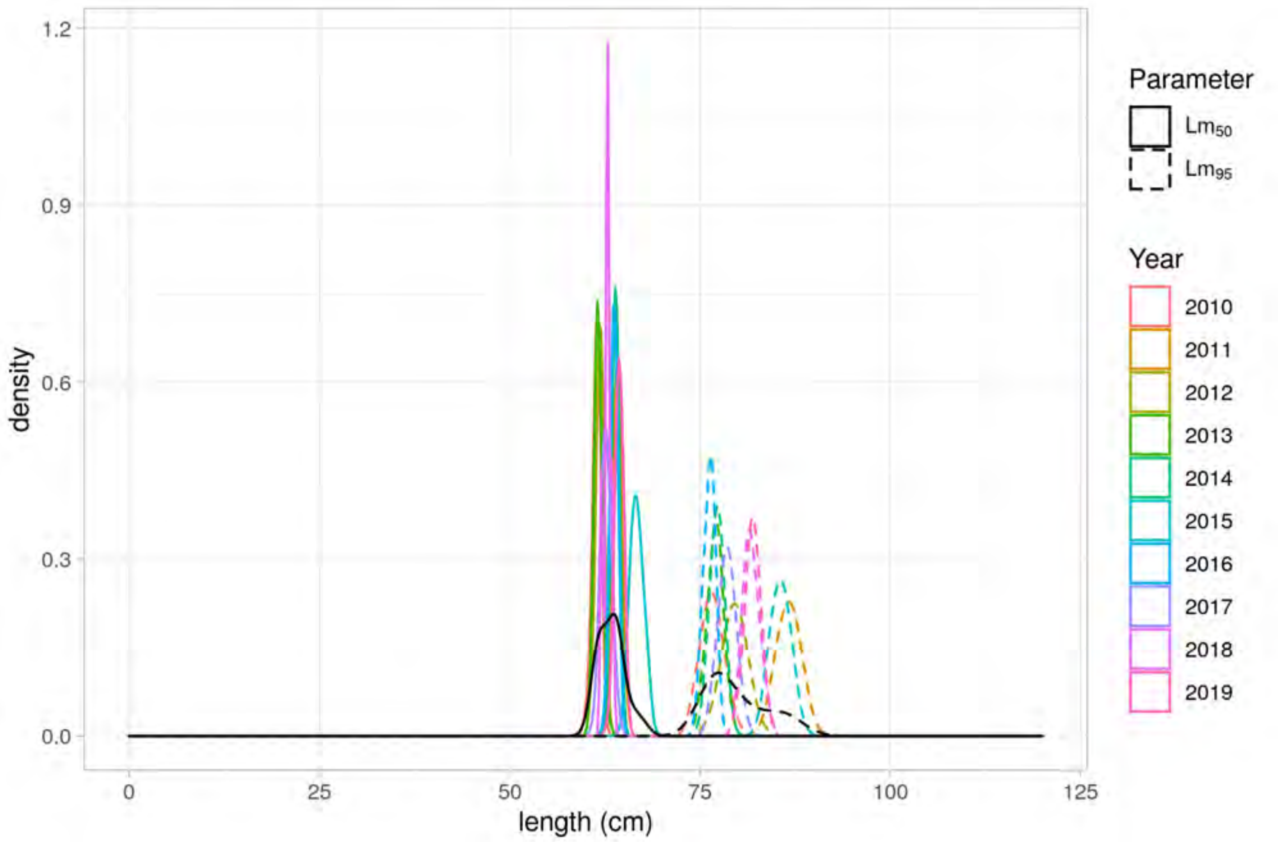

Figure 3.5. Maturity ogive parameters per year estimated for coastal cod (all data north of 62°N). Lm50 and Lm95: length at respectively 50% and 95% maturity. Based on bootstrapped data from the coastal survey and fitted using a binomial glm. The black lines represent the overall distributions of the parameters.

3.2.4 Natural mortality

One of the most critical parameters for the performance of LBSPR is M/k. Here we had first-hand growth parameter estimates but no a priori information on M/k in coastal cod. Estimating M based on life history was therefore favoured and four methods tested: one giving a constant M (Then et al., 2015, 2018b) and three size varying M estimates (Lorenzen, 1996; Gislason et al., 2010; Charnov et al., 2013). M at length values were estimated using measured individual from 10^4 bootstrapped reference fleet data sets and as many randomly generated L_∞ and k values (accounting for correlation between the two parameters). This way, genuine individual weight at length data were available for estimating M following Lorenzen (1996). Bootstrapping was performed adjusting sampling probability using weights based on gear selectivity (Gislason's and Charnov's estimates) and selectivity+size selective catch sampling (Lorenzen's estimate, based on same individuals that were aged). Size varying M estimates (Lorenzen, 1996; Gislason *et al.*, 2010; Charnov *et al.*, 2013) were re-parametrized with reference length L_∞ to match the LBSPR parametrization (Lorenzen, 2000; Hordyk *et al.*, 2016) using GLMs for each bootstrapped data set, and corresponding distributions of M/k and Mpow (aka exponent c; Lorenzen, 2000; Hordyk *et al.*, 2016) estimated for each M scenario. Note than the parameter estimates based on Charnov *et al.* (2013) unsurprisingly exhibits no variability (Table 3.1, next section) as it is strictly equivalent to assuming M = k at L_∞ and Mpow = c = 1.5 per construction.

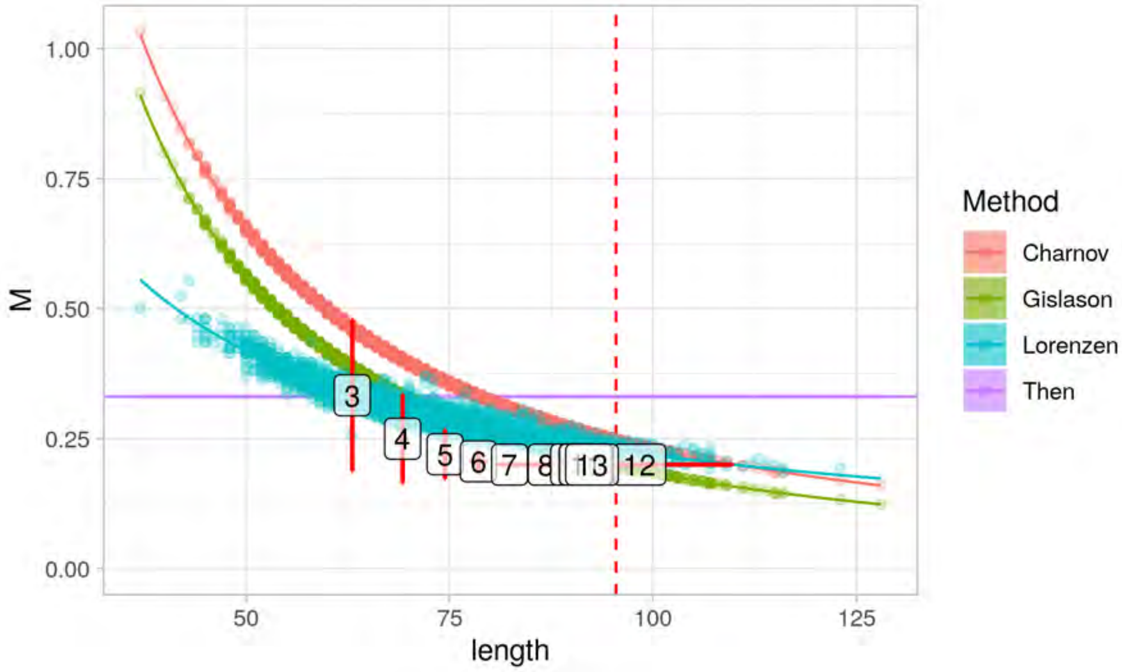

Figure 3.6. Natural mortality (M) at size of coastal cod south of 67°N, following for methods based on life histories. Based on fitted growth parameters and individual size and weights resampled from the reference fleet data. Overlaid labels and error bars (95% CI) represent mortality at age estimated based on stomach contents (cannibalism) for the partially sympatric NEA cod (2010-2020). Sizes at age are borrowed from the coastal cod south, expected to have a faster growth (Berg and Albert, 2003) and are therefore likely underestimated for younger ages.

3.3 The Length-based-spawning-potential-ratio (LBSPR) approach

The LBSPR model was fitted on 1000 bootstrapped size composition data and parameter sets. While input parameters were randomly generated/drawn as per table 3.1, the generation of the randomized data sets was two-fold:

1. random attribution of unclassified individuals between coastal and NEA cod, based on the size-based stock segregation model (section 3.1) and using a binomial random generator.
2. bootstrap of the length composition within years.

For each of the 1000 randomized data and parameter set, and each scenario, SPR, F/M and the selectivity parameter $L_{50\%}$ and $L_{95\%}$ were estimated and their resulting distributions evaluated.

Table 3.1. Parameters used to set up the stochastic LBSPR approach and their value (including uncertainty). Parameters in bold are the inputs of the LBSPR model. Other parameters not detailed here were left to their default values.

Parameter	Mean value (sd)	Description, comment
M	L: 0.228 (0.0012) G: 0.198 (0.00277) C: 0.248 (0.0032) T: 0.331 (0.0037)	Natural mortality ($year^{-1}$) at asymptotic length (L_∞). Fitted from size varying M estimates based on resampled reference fleet commercial sampling data following Lorenzen (1996; L), Gislason *et al.* (2010; G), Charnov *et al.* (2013; C) and Then *et al.* (2015, 2018; T). An additional M=0.2 scenario (M02) was also tested for comparison purpose.
	M02: 0.2 (0)	Based on 10^3 resampled reference fleet commercial sampling data sets.
Mpow	L: 0.939 (0.0042) G: 1.610 ($<10^{-10}$) C: 1.500 ($<10^{-10}$) T: 0 (0)	aka exponent c, equ. 17 in Hordyk *et al.* (2016): parametrisation of the size varying mortality in LBSPR. Fitted from size varying M estimates, following Lorenzen (1996; L), Gislason *et al.* (2010; G), Charnov *et al.* (2013; C) and Then *et al.* (2015, 2018; T). An additional M=0.2 scenario (M02) was also tested for comparison purpose.
	M02: 0 (0)	Based on 10^3 resampled reference fleet commercial sampling data sets.
k	0.248 (0.0033) *	growth coefficient from a Von Bertalanffy growth function.
M/k	L: 0.919 (0.0078) G: 0.799 (0.0007) C: 1.000 ($<10^{-10}$) T: 1.333 (0.0025) M02: 0.8057 (0.0105)	M/k at L_∞, derived from the above estimates.
Linf	95.45 (0.528) *	Asymptotic length L_∞ (cm), as defined in a Von Bertalanffy growth function.
t_0	-0.0388	Theoretical time (year) where length = 0 in a Von Bertalanffy growth function. Not a LBSPR parameter *per se*, but used for the estimation of k and L_∞ above parameters. Estimate borrowed from the coastal cod North of 67°N (EP method).
CVLinf	0.155 (0.0006)	Coefficient of variation of asymptotic length. Encompass all inter-individual growth variability in LBSPR. The values used are the CV of size at age, and its uncertainty, estimated for the coastal cod North of 67°N (EP method). Estimated and randomly generated on the log scale (mean = -1.862; sd = 0.0039).
LM50	63.36 (1.688) †	Length (cm) at 50% maturity. Estimated from resampled coastal survey data (2010-2019) using a binomial glm.
LM95	79.92 (3.924) †	Length (cm) at 95% maturity. Estimated from resampled coastal survey data (2010-2019) using a binomial glm.

*randomly generated preserving the correlation structure between k and L_∞ using a multinormal distribution.
†pairs (LM50, LM95) estimated from a same bootstrapped dataset and year drawn together to preserve the correlation between the two parameters and avoid using a parametrisation based on the distribution of ΔLm = LM95 - LM50.

4 LBSPR results and interpretation

SPR estimates based on these four different M were shown to have different absolute values but fairly similar trends (Fig. 4.1). Using the Lorenzen's (1996) M estimate, the mean SPR fluctuates between 20 and 30%, with an overall downward trend (Fig. 4.1), which places it below the target values (30-40%) and – at the end of the series – just at the limit reference point 20%, generally accepted in the absence of further information on the stock dynamics (Prince *et al.*, 2020). The relative fishing mortality F/M is estimated above 1 and follows an opposite upward trend (Fig. 4.2). The decrease in the spawning potential ratio is concomitant with a decline of size selectivity in the fleet revealed by reduction of both length at 50% and 95% selectivity (Fig. 4.3). These all together depict a somewhat depleted and worsening stock status. Other size varying M parametrisations proved even more conservative with SPR mostly below the 0.2 limit and, for the Gislason's estimate, a relative fishing mortality estimated >2. The M estimate following Then *et al.* (2015, 2018) was leading to SPR estimates consistently over 0.4 and very low relative F, but was deemed suspiciously higher than the constant M=0.2 commonly used for the assessment of cod. Comparison of the selectivity parameters estimated for different scenarios (Fig. 4.3) confirms the limited sensitivity of both $L_{50\%}$ and $L_{95\%}$ to variations of natural mortality parameters (section 3.2.1) and suggests that it applies for concomitant variations of M at L_∞ and the size-varying mortality exponent Mpow.

Among the four options examined for the parametrisation of natural mortality, the size varying M following Lorenzen (1996) was later retained based on its consistency with cannibalism-driven mortality in the partially sympatric NEA cod (Fig. 3.6). It also provides the SPR and F/M estimates the closest to a M=0.2 scenario, while there is consensus that it represents a more realistic alternative than the later.

In the absence of clear information on the stock recruitment relationship (see northern stock, main report section 3.6), more legitimate reference point cannot be estimated and even a SPR of 30% should be considered as a potentially non-precautionary level, and SPR=40% preferred (Clark, 2002; Hordyk *et al.*, 2015a).

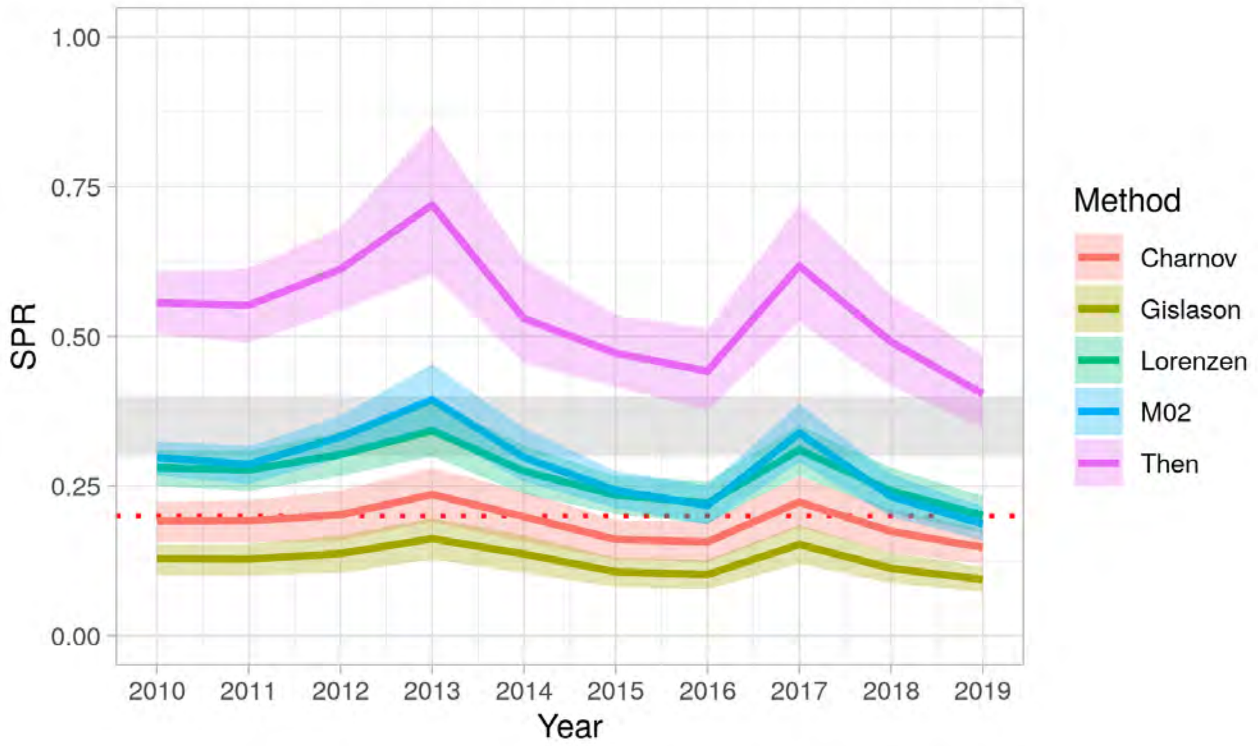

Figure 4.1. Estimated spawning potential ratio (SPR) per year for coastal cod south of 67°N. Mean (solid line) and confidence intervals (shaded red area, 95% IQR), based on the stochastic LBSPR. The grey shaded area delimits the SPR30%-40% zone (common targets) and the dotted horizontal line the SPR20% limit reference point (Prince et al., 2020).

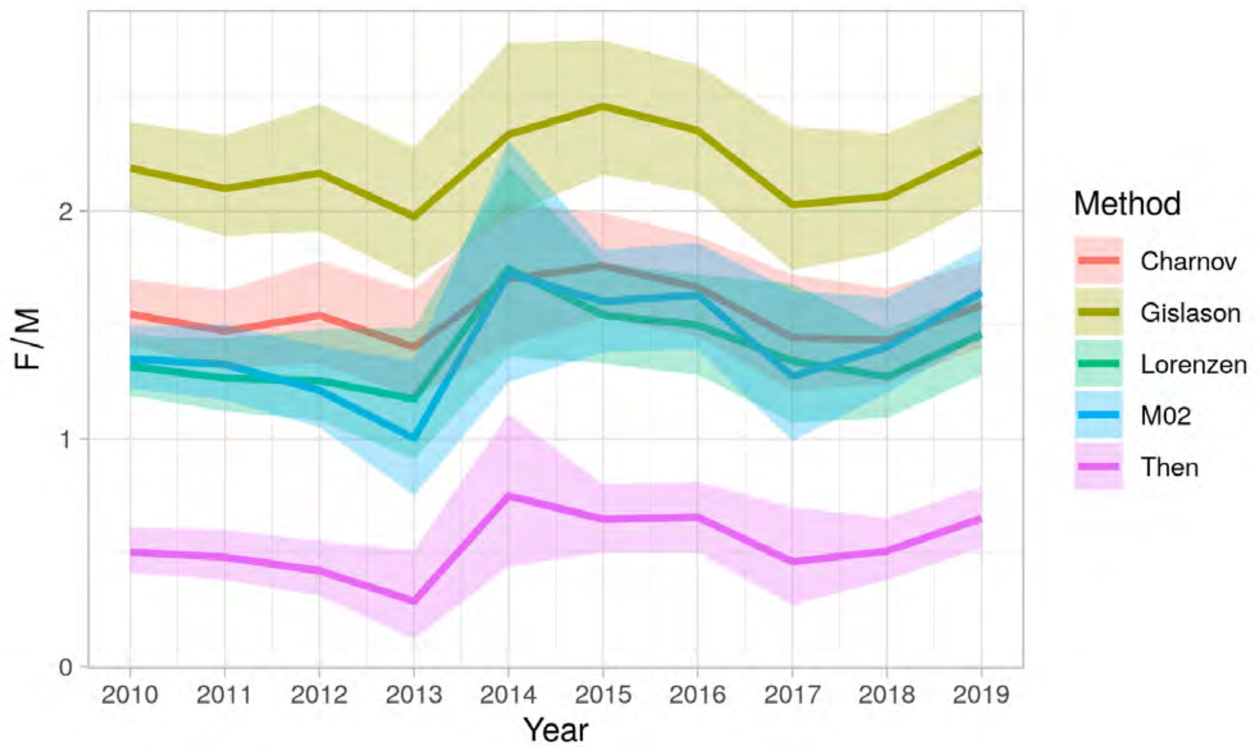

Figure 4.2. Estimated fishing mortality, relative to natural mortality (F/M) per year for coastal cod south of 67°N. Mean (solid line) and confidence intervals (shaded red area, 95% IQR), based on the stochastic LBSPR.

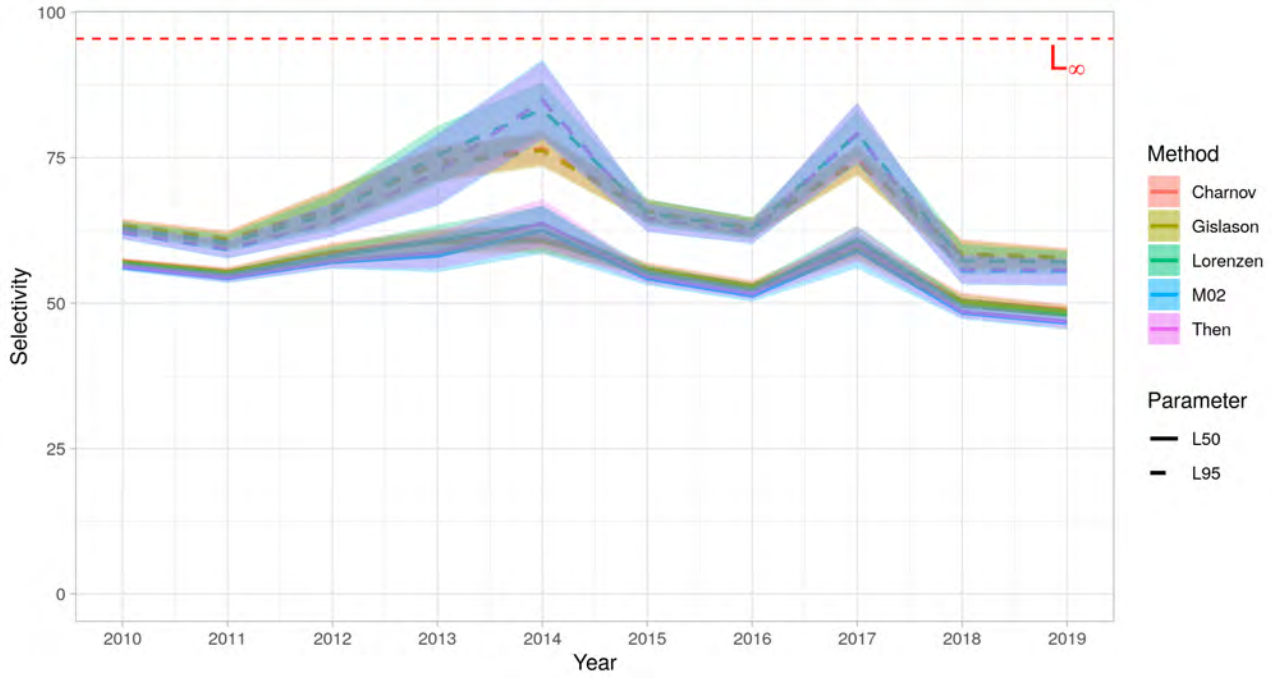

Figure 4.3. Estimated selectivity ogive parameters (size at 50% and 95% selectivity) per year for the gillnet fisheries exploiting coastal cod south of 67°N. Mean (solid and dashed lines) and confidence intervals (shaded red area, 95% IQR), based on the stochastic LBSPR.

5 Reflection on assumptions viability and additional checks

One of the key assumptions of LBSPR is that the population is at equilibrium. Whether the necessary deviations from this assumption lie in a range that does not unreasonably impair the performance for management purpose should ideally be tested using a simulation framework (Chong *et al.*, 2020). This was not done here due to time constraints and the expert group seeked for indirect evidence of strong violations instead.

Catches over the last decade have been declining (Fig. 5.1) but without strong inter-annual variations around the trend, which indicates some steadiness in the exploitation. Some years however stand out when it comes to selectivity within the gillnet fisheries (Fig. 4.3). 2013-14 and 2017, for instance, exhibit a flatter selectivity (higher L_{50} and larger L_{95}-L_{50} difference) which will promote an immediate overestimation of the SPR on those years by assuming (under the equilibrium assumption) a larger portion of the SSB to be unaffected by fishing than actually is. Those years with flatter selectivity should therefore be interpreted with extra caution as the expected bias is not conservative. Trends and stock status were confirmed using the size-based indicator $L_{max5\%}$, less sensitive to changes in selectivity, and its corresponding $L_{max5\%}^{SPR=40\%}$ reference point (Miethe *et al.*, 2019) (Fig. 5.2), indicating that these variations in selectivity are likely not affecting the overall picture.

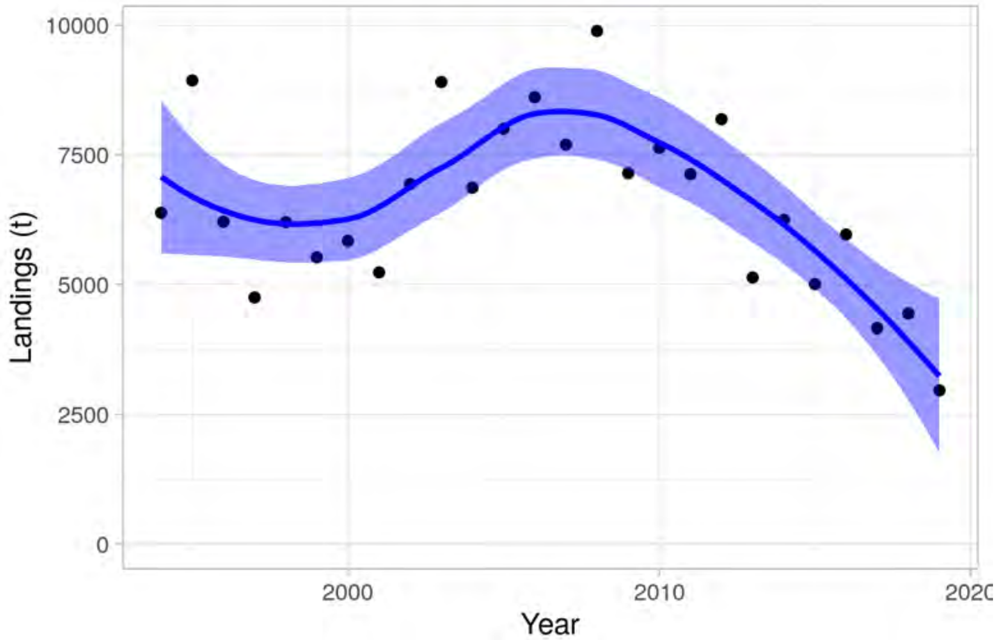

Figure 5.1. Commercial landing per year (tonnes) estimated for coastal cod south of 67°N. Trend based on a GAM smoother.

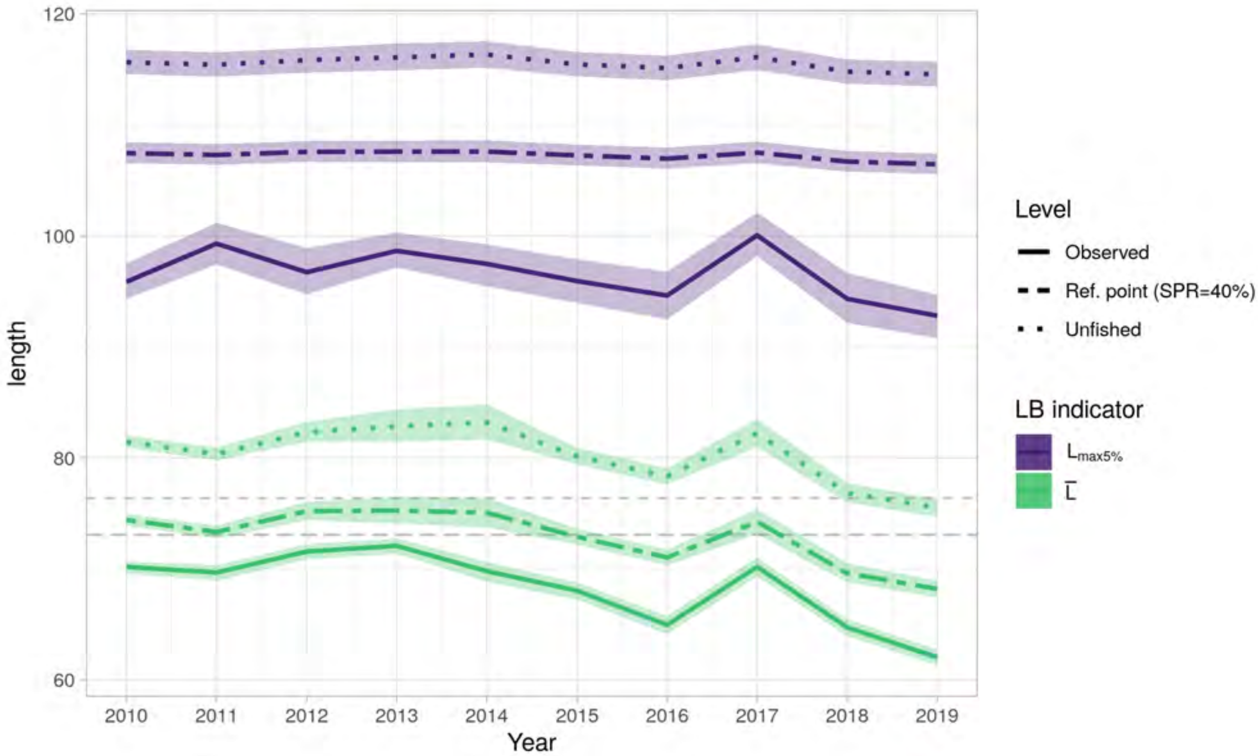

Figure 5.2. Variations in time of the size-based indicators $L_{max5\%}$ and mean length in catch ($\bar{L}$), and their reference points (mean and 95%CI). The reference points points were estimated using the LBSPR simulation model together with the stochastic parameters detailed in Table 3.1 (mortality scenario following Lorenzen, 1996) and SPRs of 40% and 100% (unfished).

Another key assumption of the model, as formulated in the LBSPR package, is asymptotic selectivity. We checked the absence of obvious dome-shaped selectivity by comparing the right side of size distributions in commercial catches and the coastal survey. $L_{max5\%}$, which gives an indication of where the right side of the size distribution stands, did not differ significantly between the two data sources when comparing distributions estimated from bootstrapped data (Fig. 5.3). This cannot however rule out the scenario of a similar dome-shaped selectivity / catchability in both data sources.

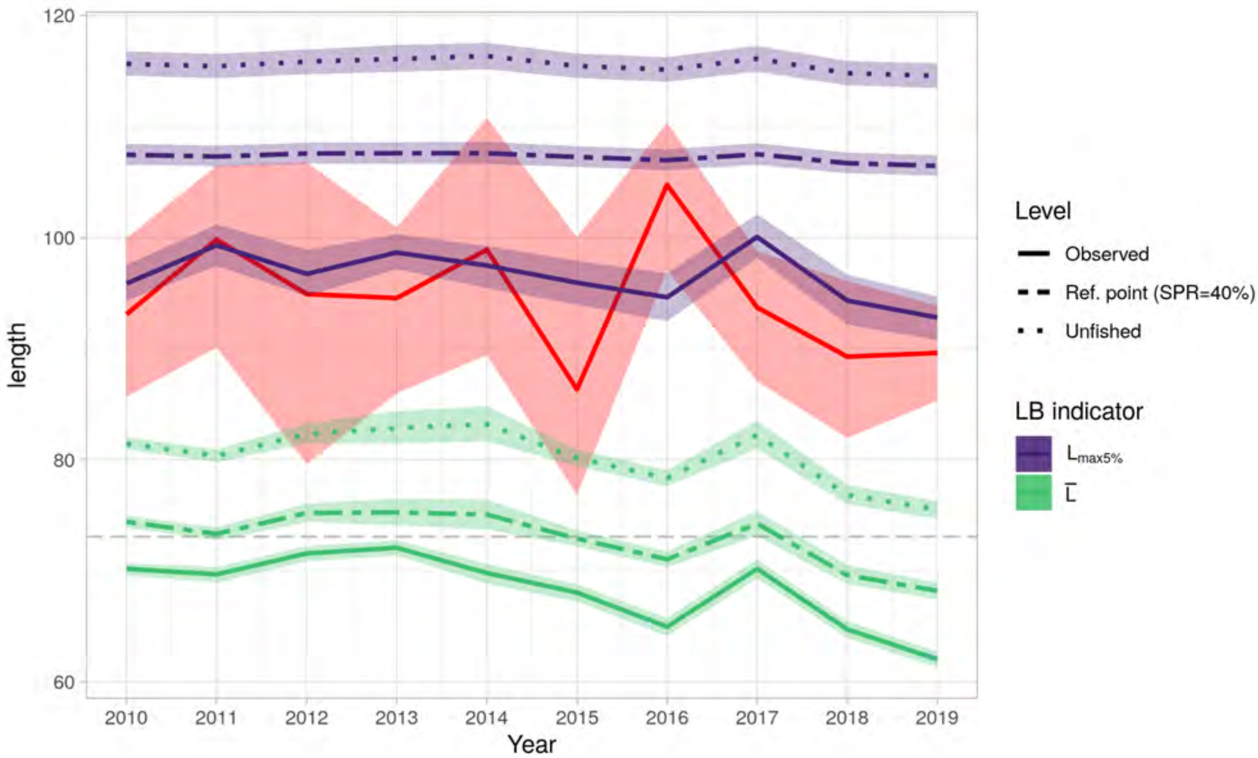

Figure 5.3. $L_{max5\%}$ per year in the coastal survey south of 67°N (mean, solid red line and shaded 95% CI) overlaid on estimates from the reference fleet, as presented in Fig. 5.2.

Further checks were suggested during the review process, among which a comparison of the total mortality Z, estimated using different M scenarios. Distributions of Z at L_∞, calculated using the stochastic F/M estimated by LBSPR as $Z = M(1 + F/M)$, were compared among the scenarios and are represented in Fig. 5.4. Total mortality in the Lorenzen's M scenario was mostly overlapping the estimates for the constant M scenarios, except in those years where the selectivity in the reference fleet was exhibiting unusual patterns (2013-2014, 2017). The Gislason's and Charnov's size varying scenarios had very similar Z, substantially higher than for other scenarios over the whole period. These Z are however not representative of the overall population mortality in the case of size varying M, as they are point estimates at L_∞, and are as a consequence not directly comparable. The observed differences did not raise particular concerns during the review process. Z values estimated using catch curve analysis were found to be larger than the estimate based on the Lorenzen's M scenario, but here again, values are not directly comparable as this last is based on M at L_∞ (around age 10+, Fig. 3.6) while the catch curve analysis encompass individuals from age 5 years, thought to have a higher M. Further investigations are therefore needed for a legitimate comparison of these values.

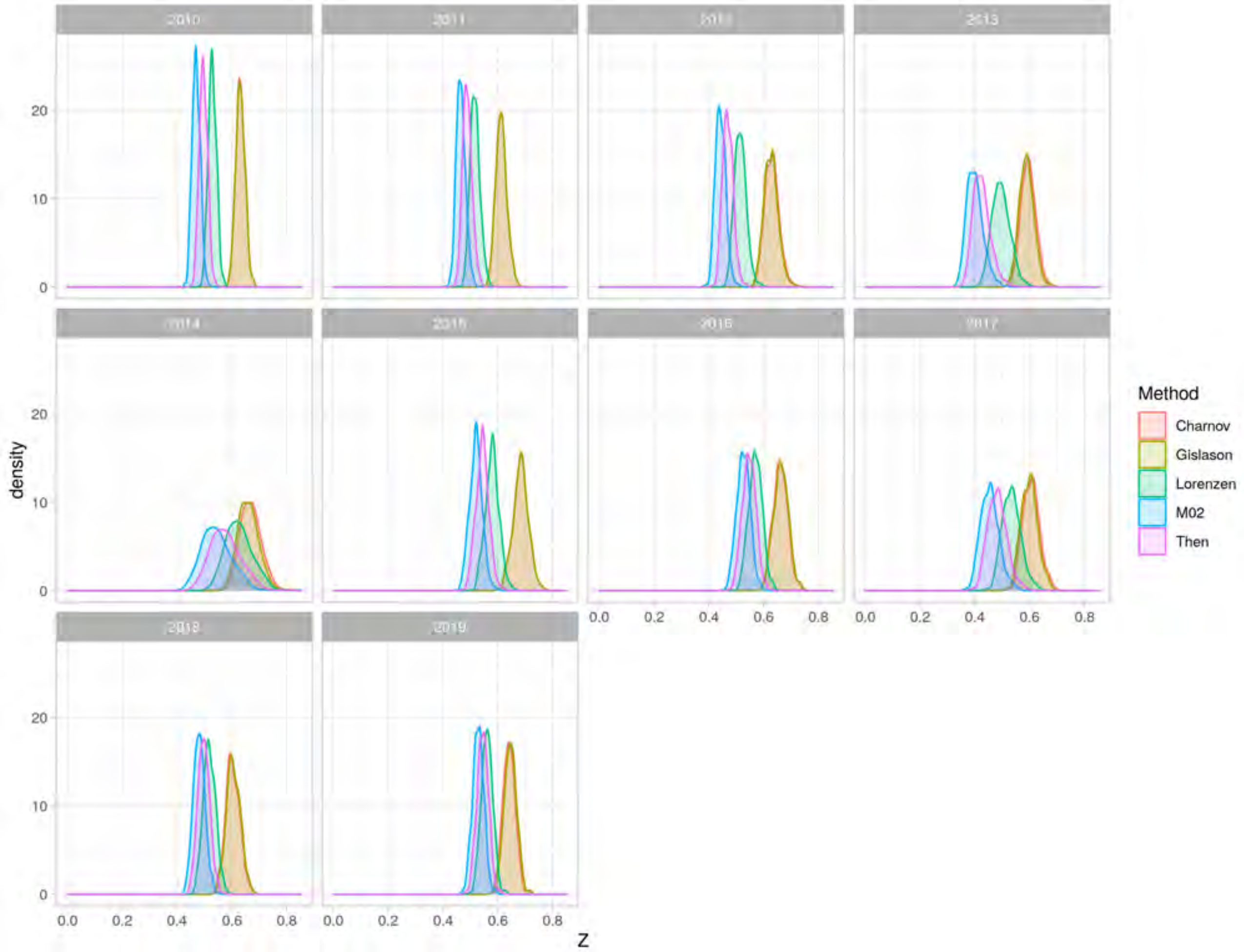

Figure 5.4. Total mortality Z distribution per year and per scenario.

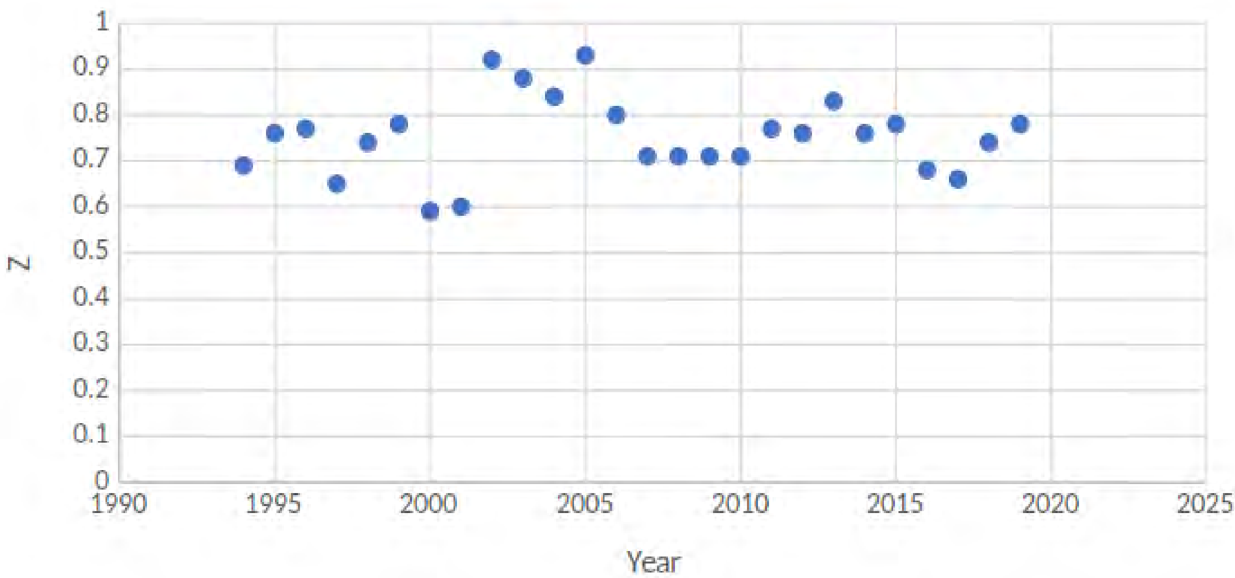

Figure 5.5. Total mortality Z estimated from catch curves (ages 5-14) 1994-2019, for coastal cod between 62 and 67°N.

6 References

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Estimating the status of coastal cod (*Gadus morhua*) north of 62˚N (ICES Subarea 2) using CPUE data from the Norwegian coastal reference fleet

by
Kotaro Ono, Sofie Gundersen, Yves Reecht and Kjell Nedreaas

Institute of Marine Research, PB-1870, N-5817 Bergen, Norway

Introduction

In the coastal areas north of 62˚N (ICES Subarea 2.a.2; Norwegian statistical areas 00, 03, 04, 05, 06 and 07) coastal cod are identified from the growth pattern in the ear stones (the otoliths, Rollefsen 1932). This is done by random sampling from the fisheries. Based on this sampling, cod catches per gear, area and quarter in retrospect (when the fishing year is over) are split into coastal cod (NCC) and Northeast-Arctic cod (NEAC). For cod younger than 2 years the otoliths contain too little information to make a reliable distinction between NCC and NEAC. These age groups are only sporadically represented in commercial fishing, but may in some areas be included in the recreational and tourist fishing. For 0-1 year old it is only genetic analyses that can clarify whether it is coastal cod or Northeast-Arctic cod.

The separation into two main cod groups, NCC and NEAC, was supported by the genetic studies of Møller (1968, 1969). Recent studies that have compared the results from genetic studies, tagging experiments and otolith patterns, have led to the same conclusion that the two groups should be considered as separate populations (Jakobsen 1987, Dahle 1991, Dahle *et al*. 2018). Coastal cod differs also from Northeast Arctic cod in terms of life history parameters, which, however, also show differences between areas (Berg and Albert 2003).

The genetic differentiation between coastal cod populations along the Norwegian coast is mainly gradual, a cline from south to north (Dahle et al 2018). There seems, however, to be a barrier at about 62N and in the Lofoten area. For reasons of geographical coverage in the cruises, it seems more appropriate to set this limit at 67N. For coastal cod north of 67N, we consider that the data base is good enough to develop an analytical stock assessment in a similar way as for NEAC. This northern area also contributes more than 80% to the total catch of coastal cod north of 62N.

The Norwegian cod TAC is a combined TAC for both the NEAC stock and NCC stock. Landings of cod are counted against the overall cod TAC for Norway, where the expected catch of coastal cod is in the order of 10%. There are no separate quotas given for the coastal cod for the different groups of the fishing fleet. Catches of coastal cod are thereby not effectively restricted by quotas. Since the coastal cod is fished under a merged coastal cod/northeast Arctic cod quota, the main objective of these regulations is to move the traditional coastal fishery from areas with high fractions of coastal cod to areas where the proportion of NEA cod is higher.

The Norwegian Reference Fleet is a group of active fishing vessels tasked with providing information about catches (self-sampling) and general fishing activity to the Institute of Marine Research. The fleet consists of both high-seas and coastal vessels that cover most of Norwegian waters. The High-seas Reference Fleet began in 2000 and was expanded to include coastal vessels in 2005 (e.g., Clegg and Williams 2020). The Norwegian coastal reference fleet in 2020 is shown in Appendix figure 1, and the different gillnet types in Appendix figure 2. Catch operations with cod and predicted proportions of coastal cod in the catches are shown in Figures 1 and 2, respectively.

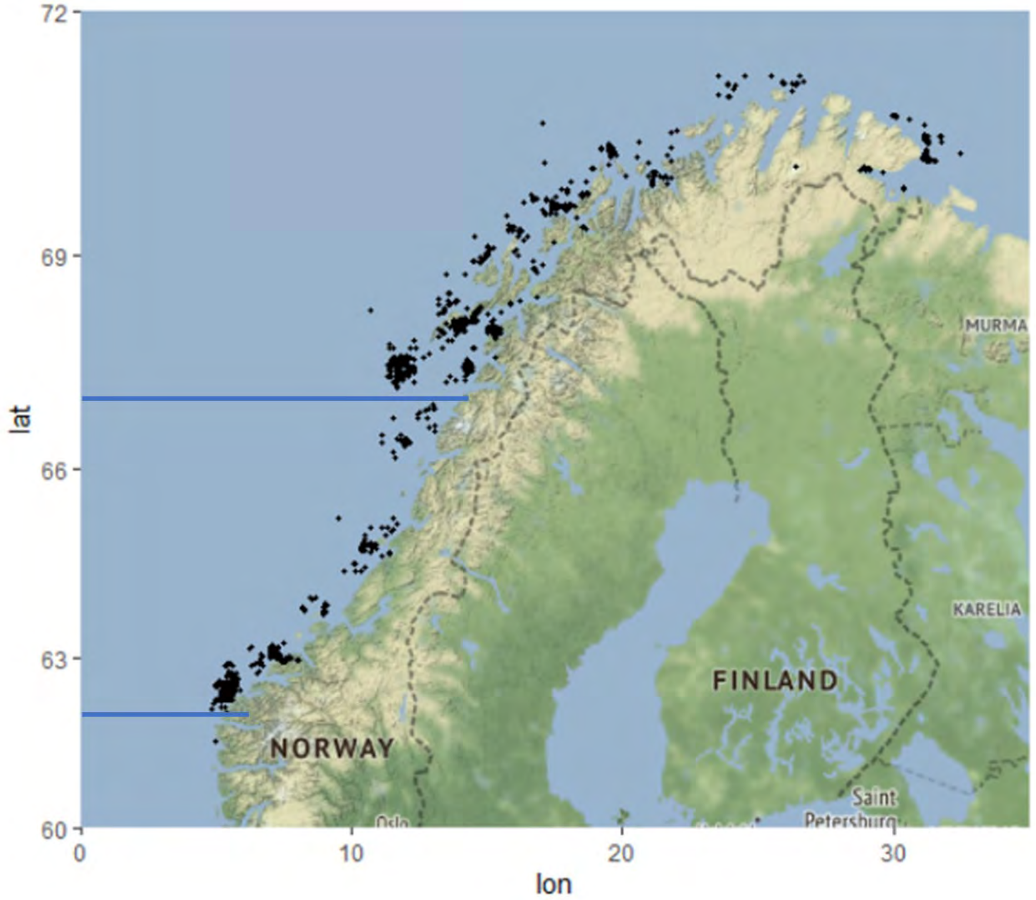

Figure 1. Catch operations with catches of cod by the Norwegian coastal reference fleet during 2007-2019. The blue lines denote the 62nd and 67th latitudes, respectively.

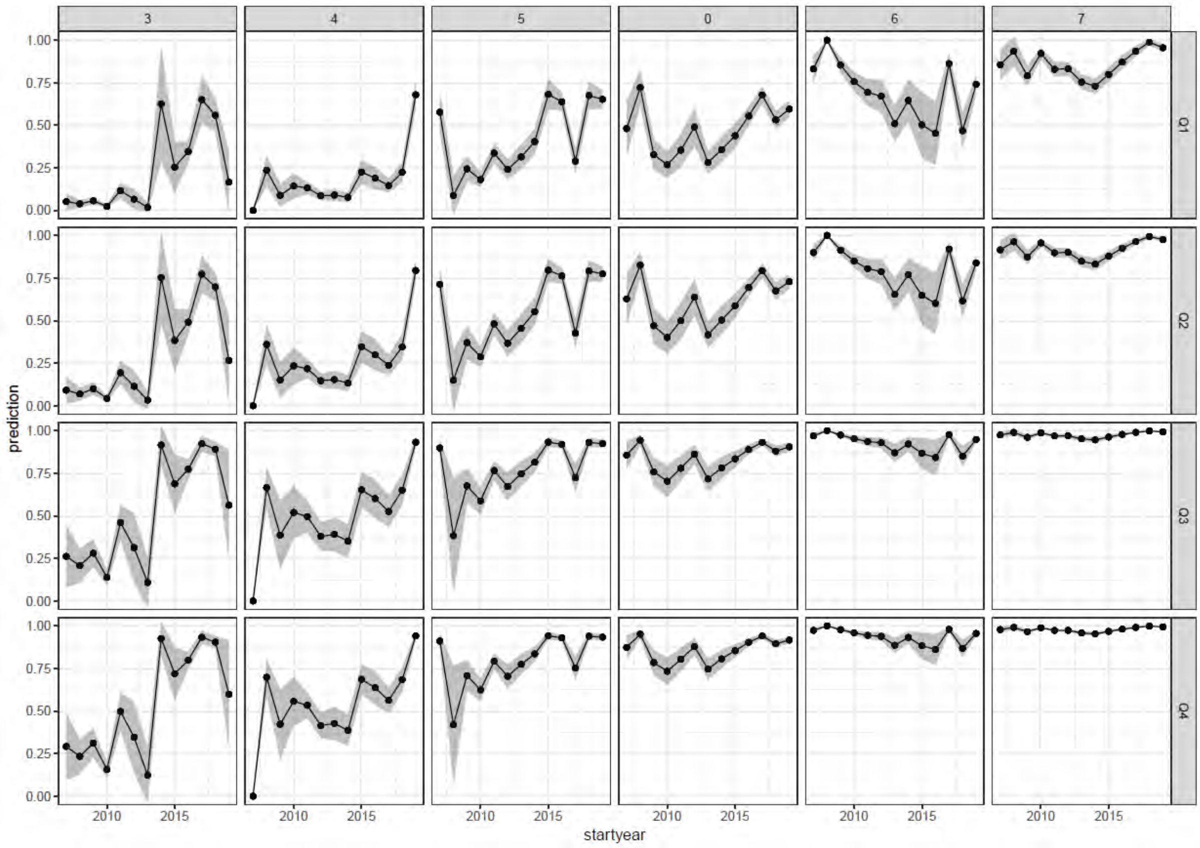

Figure 2. Predicted proportions of coastal cod in the coastal reference fleet catches by statistical area and quarter during 2007-2019 based on otolith classification using ALL otolith categories, i.e., 1,2 = coastal and 3,4,5,6 = NEAC. The increasing year trend in the northern areas (3, 4 and 5) is also related to changes in fishery regulations allowing more cod to be caught during autumn months when most of the cod on the coast is coastal cod. The shaded polygon is the 95% confidence interval for the prediction.

Although we show in Figure 2 some prediction on coastal cod catch ratio in all areas and quarters, in the CPUE analysis presented below we specifically focus on area 6&7 and quarter 3&4 because we believe that is the best data to inform about cod status.

Catch per unit effort (CPUE) data

The Norwegian coastal reference fleet has reported catch per gillnet soaking time (CPUE) from their daily catch operations. The genetic differentiation between coastal cod populations along the Norwegian coast is mainly gradual, i.e., a cline from south to north (Dahle et al 2018). There seems, however, to be a barrier at about 62N and in the Lofoten area at about 67N. Based on the current stock situation, there seems also to be a need for stricter regulation measures south of 67˚N, i.e, in the national subareas 6 and 7, than north of this latitude (Aglen et al. 2020). For the current modelling and hence standardization of the annual CPUE from Subarea 6 and 7, we have used the following data:

- Only catch rates of retained cod from the fishery using gillnets except the anglerfish gillnet, i.e., discards excluded
- Years 2007-2019
- Adding zero catches where gillnets are used, but cod not present
- Focusing on area 6 and 7 (though, for statistical estimation purpose, data from areas 3, 4, 5,0, 6, 7 could be used altogether, then the output narrowed down to area 6 and 7)
- Focusing on quarters 3 and 4 to avoid the largest aggregations of spawning NEAC temporarily inhabiting coastal areas and mixing with NCC
- The area (km^2) of each subarea inside 12 nautical miles (covering most of the coastal cod distribution) are calculated and used as weighing factor when annual CPUEs are estimated for each subarea.

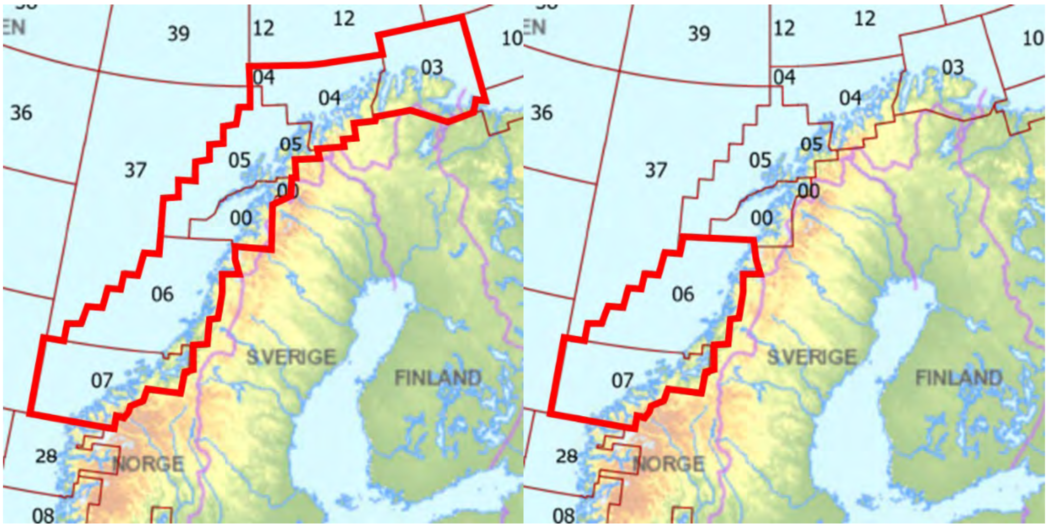

Figure 3. Norwegian statistical areas. Area 03 is part of the ICES Subarea 1 and areas 28 and 08 are part of ICES Subarea 4. The other areas belong to ICES Subarea 2.

CPUE standardization

Raw CPUE data is seldom proportional to population abundance as many factors (e.g. changes in fish distribution, catch efficiency, effort, etc) potentially affect its value. Therefore, CPUE standardization is an important step that attempts to derive an index that tracks relative population dynamics.

There are two cod stocks (two ecotypes) that are mixed together in the Norwegian waters: the coastal cod (NCC) and the Northeast Arctic cod (NEAC). In this working document, our interest lies on deriving the abundance index of coastal cod, therefore, a few steps need to be taken to derive the corresponding coastal cod abundance index:

1. Fit a model to determine whether an individual fish is categorized as coastal or NEAC. This step allows determining the probability of catching coastal cod vs NEAC during the time frame of interest
2. Perform a CPUE standardization using the data from the reference fleet
3. Use the output form the above steps and create an index of abundance

Below, we defined some important terms we used for the CPUE standardization.

Standardized effort (gillnet day) = gear count x soaking time (hours) / 24hours
CPUE (per gillnet day) = catch weight/standardized effort

<u>Step1: Coastal cod vs. NEAC?</u>
In order to determine the origin of cod, we used all data from above 62^{0}N (i.e. areas 3, 4, 5, 0, 6, 7) with information on otolith type. The later is the source of identification which helps separate between coastal vs. NEAC. Otolith type 1 and 2 were categorized as "coastal" and type 3, 4, 5, 6, as NEAC. A total of 27800 samples were used for the analysis between 2007-2019.
From the above samples, we removed any covariates that had less than 3 observations to ensure estimability (the covariate in question was mostly the gear type) (the final sample size was N=27795). We then fitted a binomial model with logit link using 4 different explanatory variables: year, area, quarter, and gear, using the following formula:

*Glm1 <- glm(is_coastal ~ factor(area)*factor(startyear) + factor(quarter) + factor(gear), family=binomial, data=Data_proportion)* (eq1)

In this process, we also tried fitting different covariate configurations as well as trying to use only the data from area 6 and 7 i.e. the main focus area (N=1686), but these resulted in model with more problematic residuals pattern (at least, significantly worse). Therefore, we are only presenting in this document the final model configuration and outputs.

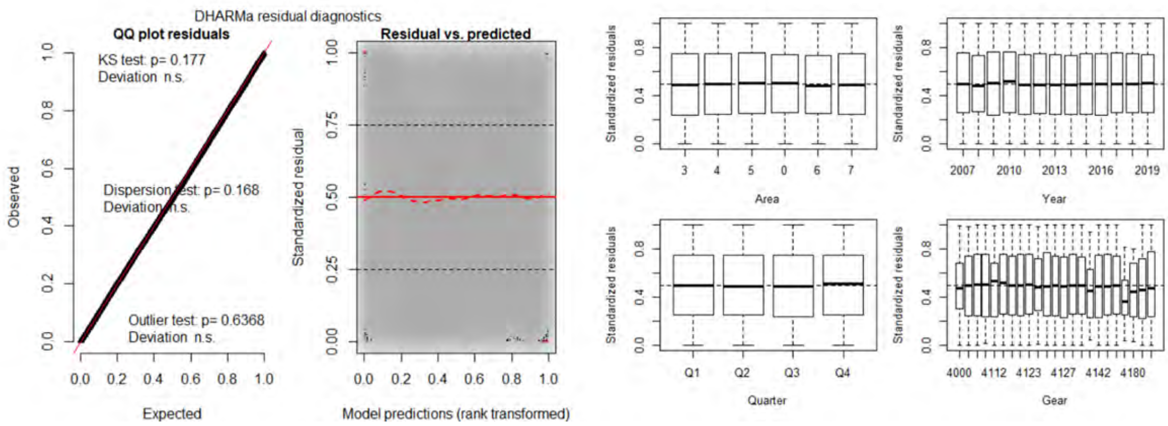

Figure 4. Residual diagnostic plots for the final binomial model to differentiate coastal cod vs. NEAC. The panel on the left is a standard output from the residual diagnostics using the R package DHARMa. The panel on the right plots the model standardized residuals against available covariates. Both panels indicate no significant issues with the final model.

Using the above model, we then predicted the proportion of coastal cod we would be expecting in area 6 and 7, during quarter 3 and 4, between 2007-2019.

During the prediction process using the final binomial model (eq 1), we used the gear code 4140 as the basis for prediction because this gear effect was estimated to be close to 0. It is to be noted that the gear effect mostly shifts the whole curve up and down. Another remark is that a similar model to eq 1 but with gear as random effect was also run using the R package glmmTMB but model residual pattern was much worse than the final model, thus not explored further. The main reason behind this difference was that the estimated gear effect was not normally distributed and there were some gears with much higher chance of catching coastal cod (i.e. gear code 4145 and 4180) (Figure 5). For information, gear code 4145 are unspecified demersal gillnets of 120 mm half mesh size (240 mm stretched mesh), and 4180 are demersal monofilament demersal gillnets of 68 mm half mesh size (136 mm stretched mesh).

The prediction suggested that the proportion of coastal is generally very high in area 6 and 7 during quarter 3 and 4 (with some slight annual fluctuation in area 6).

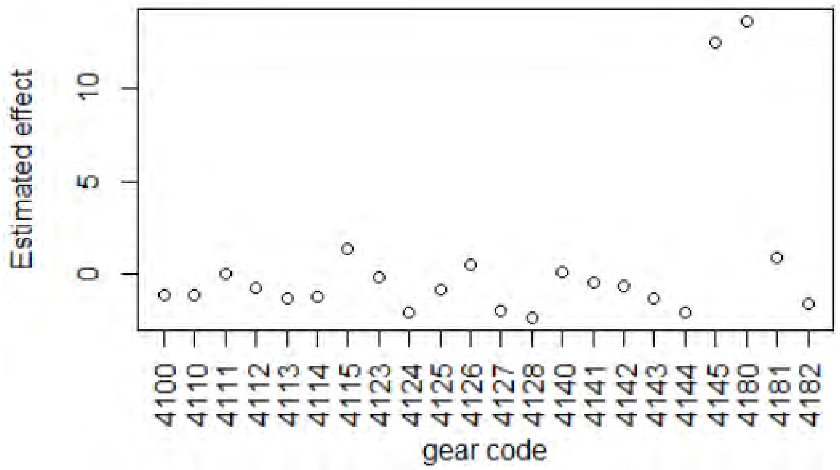

Figure 5. Estimated gear effect from the final binomial model. See also Appendix figure 2.

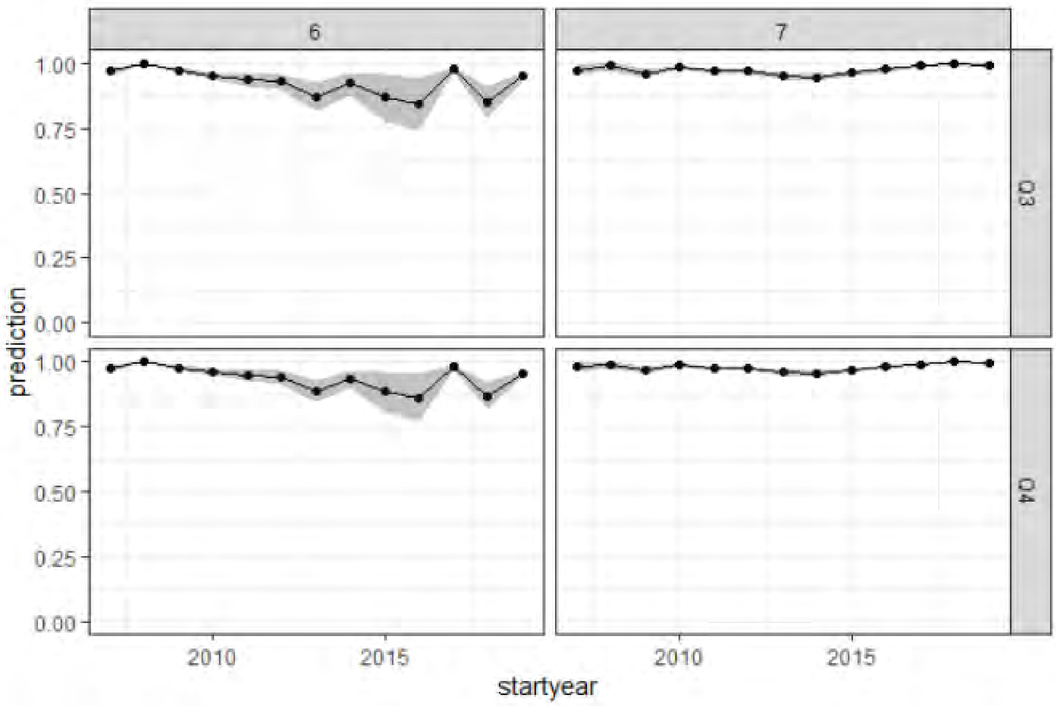

Figure 6. Predicted probability of catching coastal cod based on the quarter (vertical panels), areas (horizontal panels), and years (x axis within each panel). The grey shaded polygon represents the 95% confidence interval.

Step2: CPUE standardization

Many different R packages (e.g. mgcv::gam, glmmTMB::glmmTMB, sdmTMB::sdmTMB, and own model in TMB to allow implementing a mixture model), as well as many different combination of likelihood functions (e.g. normal, lognormal, gamma, negative binomial, student t, tweedie), zero inflation, and parameter were tested to find a model which showed an acceptable residual pattern. However, model exploration was not conclusive when using the entire CPUE data from area north of 62^{o}N (N=11805, with only 59 zeros). All the model struggled fitting the extremely skewed CPUE data (many extremely small values below 1 and large values above 1000, while the bulk of the values are in the scale of dozens).

The final model for the CPUE standardization was fitted on all cod data (no distinction between coastal and NEAC yet) but limited to area 6 and 7 and quarters 3 and 4, between 2007-2019. Further data filtering was performed to remove erroneous data point (e.g. gearcount =1) and any gear code with less than 3 observations. This reduced the final data set to N=625 (with only 3 zeros):

```
glmmTMB_pos <- glmmTMB(log(cpue_all) ~ factor(startyear)
 + factor(area) + factor(gear) + factor(quarter) + (1|area_year)          (eq 2)
 + (1|quarter_year), family = gaussian, data=subset(nord_use, cpue_all>0))
```

The expression (1|area_year) indicates that the area and year variable was concatenated into a single variable and considered as a random effect acting on the intercept. In essence, this treatment models the interaction effect between year and area on the intercept, but the approach only considers existing interaction (as opposed to all possible combination of year and area which would be un-estimable) – which is an advantage in data-limited situation such as ours.

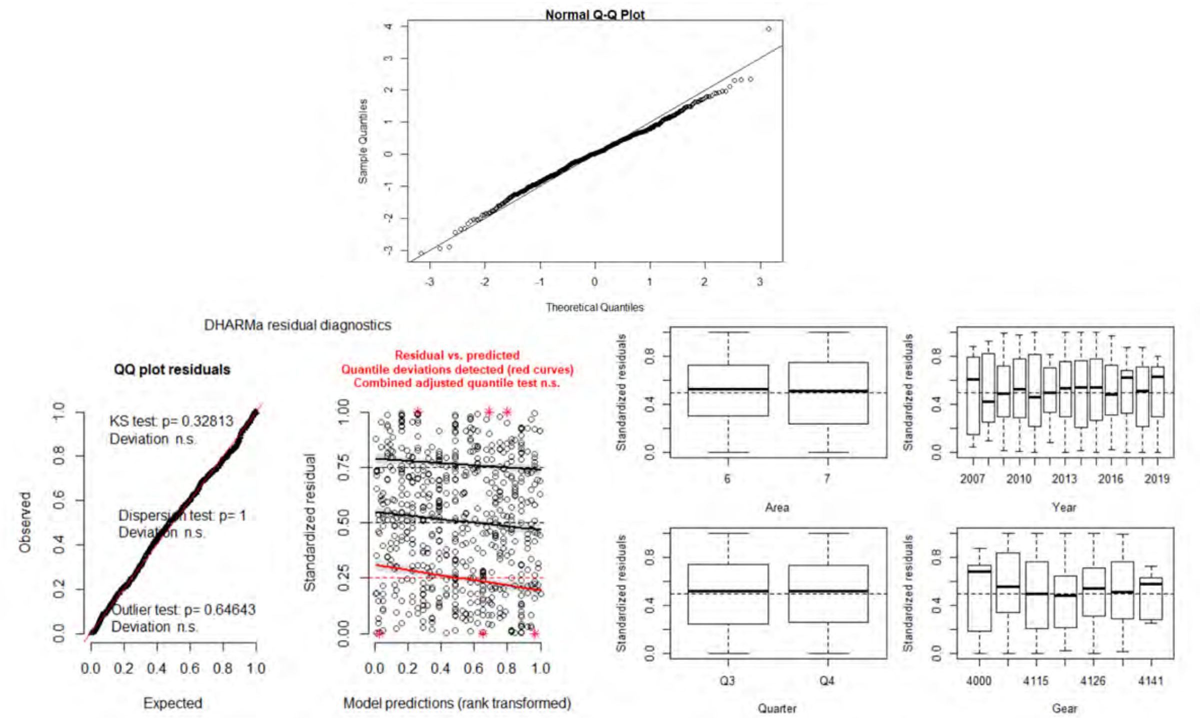

Figure 7. Residual diagnostic plots for the final CPUE model fitted to cod data in area 6 and 7, and quarters 3 and 4. The top panel is the normal QQ-plot. The panel on the left is a standard output from the residual diagnostics using the R package DHARMa. The panel on the right plots the model standardized residuals against available covariates. All panels indicate no significant (though some) issues with the final model.

Joining step 1 and 2 to create a standardized coastal cod CPUE

The final cod CPUE model showed a reasonable residual behavior (Figure 7) and therefore, we proceeded with the derivation of the standardized coastal cod CPUE index for area 6 and 7 and quarters 3 and 4.

The standardized coastal cod index ($CPUE\_std_{coastal}$) was calculated as:

$$CPUE\_std_{coastal} = P_{coastal} * CPUE_{cod} \qquad \textit{(eq 3)}$$

Where $P_{coastal}$ is the predicted proportion of coastal cod in the catch based on the output from step1, and $CPUE_{cod}$ is the predicted cod (of both ecotypes) CPUE based on step 2.

And the variance of ($CPUE\_std_{coastal}$) was calculated as:

$$V(CPUE\_std_{coastal}) = \left(\widehat{P_{coastal}}\right)^2 V(CPUE_{cod}) + \left(\widehat{CPUE_{cod}}\right)^2 V(P_{coastal}) \qquad \text{(eq 4)}$$

Some combinations of area_year and quarter_year random interaction effect were not present in the datasets for the CPUE standardization model. However, glmmTMB can handle any missing new levels of random effect variables when making prediction (it assumes it is equal to zero and inflates the prediction error by its associated random effect variance).

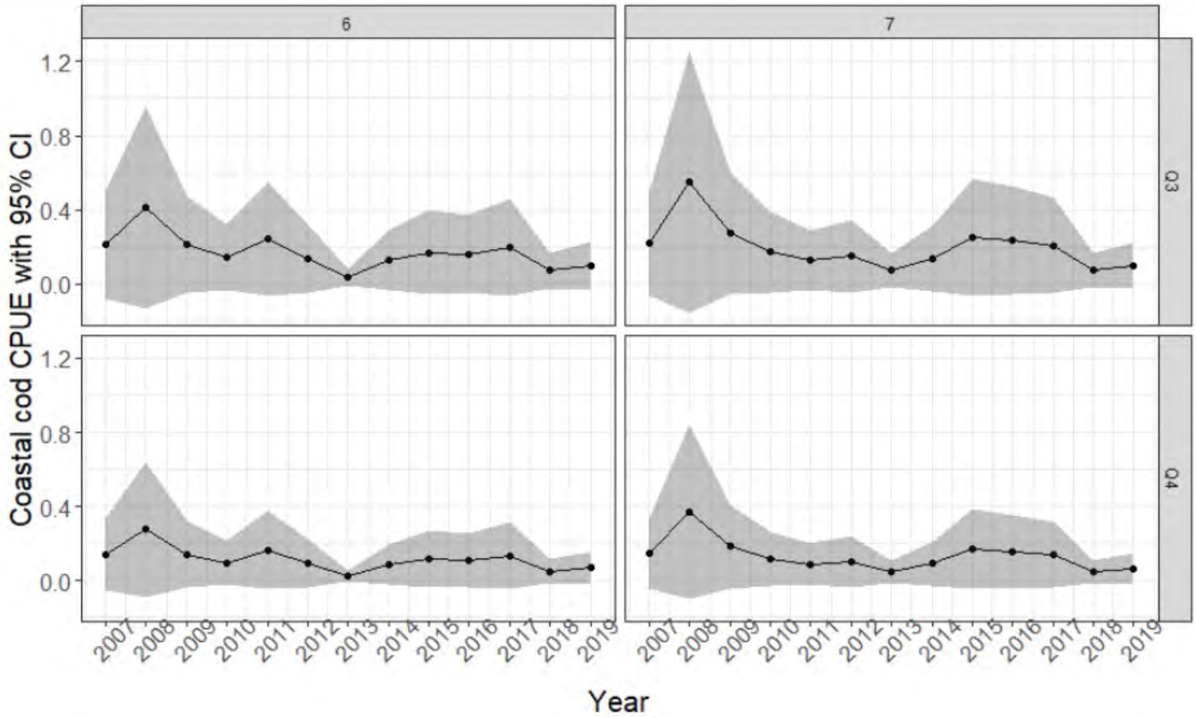

Figure 8. Standardized CPUE index for coastal cod in area 6 and 7 during quarters 3 and 4, between 2007-2019. The grey shaded polygon represents the 95% confidence interval.

The final standardized CPUE index for coastal cod indicates a general declining trend in all areas and quarter since 2007 with some inter-annual variability.

Additional analysis

Any of the following analysis should **NOT** be used for management purpose as the results are not final. Model diagnostics shows some issues with model fit to data, therefore the derived abundance index cannot be trusted. We are writing this section for illustrative purpose and we highly recommend further analysis to be conducted to obtain more robust methods.

In the following, we performed the same kind of analysis as above except that we used all data above 62N and limited to Q3 and Q4 (N=2160, with 16 zeros) for the CPUE analysis. However, no model was satisfactory in terms of residual behavior. Nonetheless, we will present the result of one of the least problematic case:

```
glmmTMB_pos <- glmmTMB(log(cpue_all) ~ factor(startyear)
 + factor(area) + factor(gear) + factor(quarter) + (1|area_year)        (eq 5)
 + (1|quarter_year), family = gaussian, data=subset(nord_use, cpue_all>0))
```

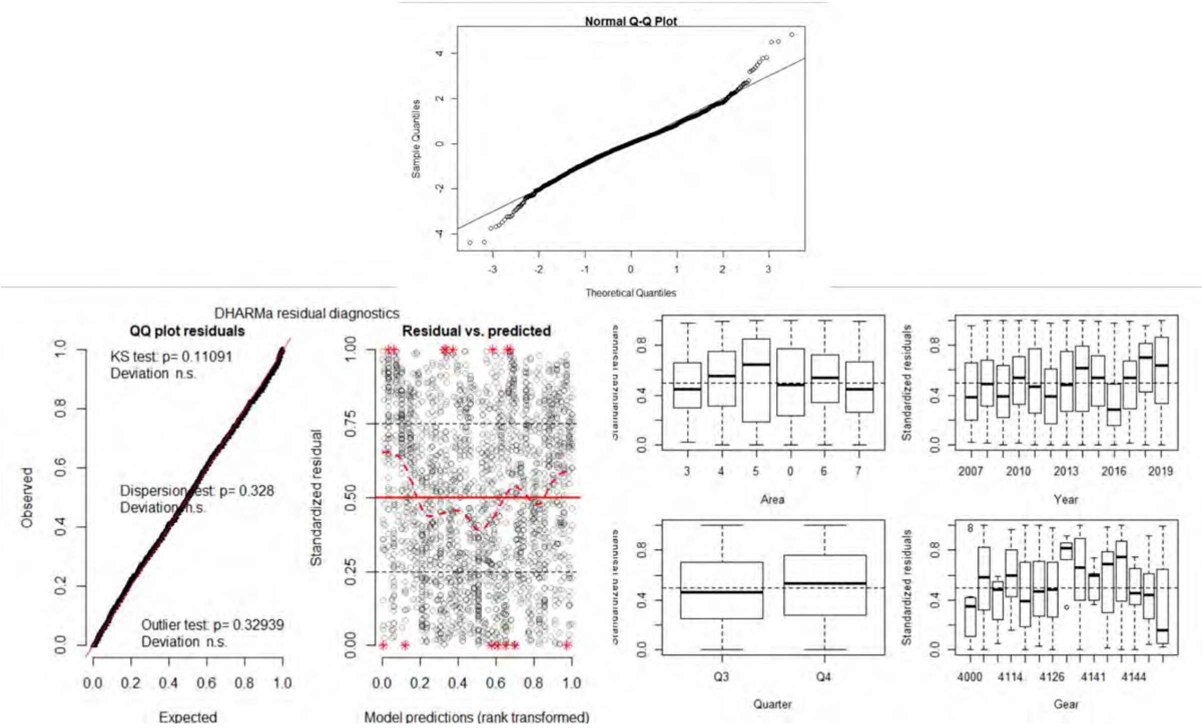

Figure 9. Residual diagnostic plots for the final CPUE model fitted to cod data in all areas above 62N and quarters 3 and 4. The top panel is the normal QQ-plot. The panel on the left is a standard output from the residual diagnostics using the R package DHARMa. The panel on the right plots the model standardized residuals against available covariates. These panels reveal some issues with model fit to data (especially with the prediction of small and large values).

Standardized CPUE index for coastal cod for areas 3, 4, 5, 0, 6, and 7 were also calculated following the same approach as in eq 3, 4 (Figure 10).

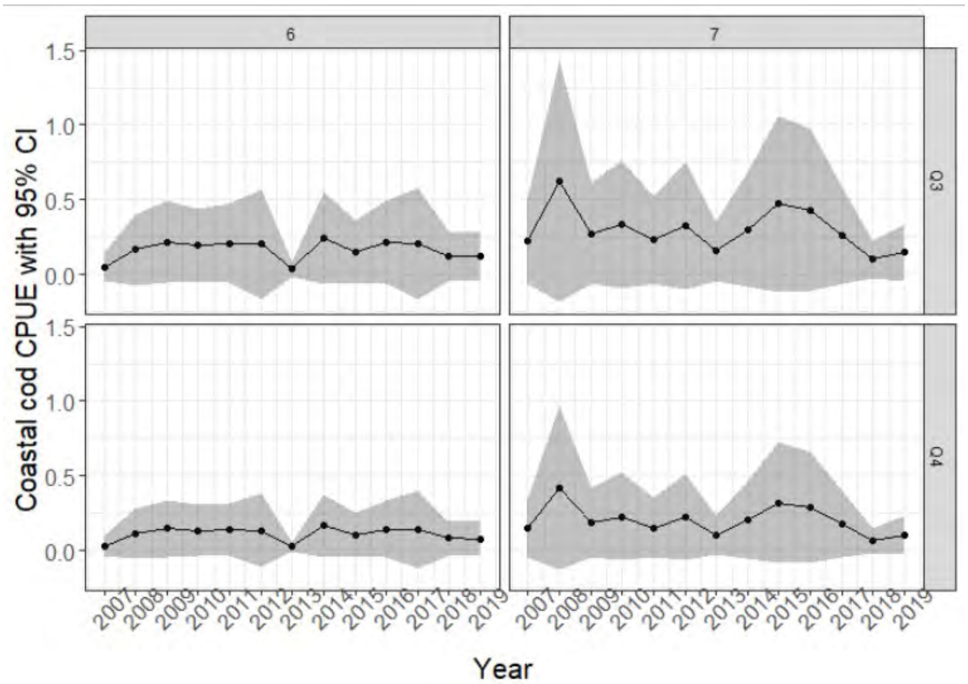

Figure 10. Illustrative standardized CPUE index for coastal cod in area 6 and 7 during quarters 3 and 4, between 2007-2019 using the “problematic” model. The grey shaded polygon represents the 95% confidence interval.

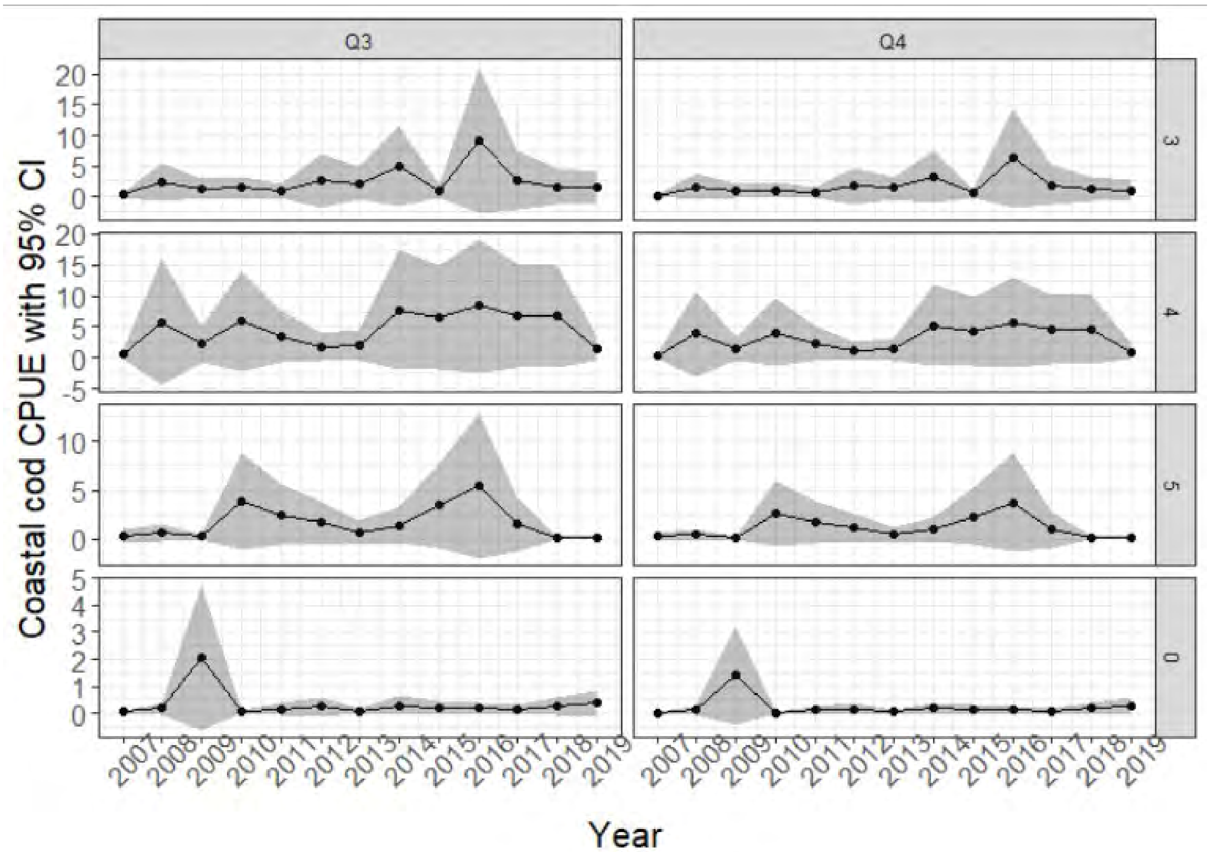

Figure 11. Illustrative standardized CPUE index for coastal cod in area 3, 4, 5, 0 during quarters 3 and 4, between 2007-2019 using the “problematic” model. The grey shaded polygon represents the 95% confidence interval.

Future tasks & improvement

There were obvious issues when trying to develop the CPUE standardization model for cod in Norwegian waters when including data above 67N i.e. the model did not fit the data well as supported by the residuals diagnostics plots.

Such analysis should further be pursued in the future with the focus to improve the CPUE model fit to cod data in order to derive a more “reliable” index of abundance.

There are a few possible investigations we suggest for future research:

1. further refinement of the data to use
2. collecting information such as species composition of the catch. Such information could be very valuable in order to account for targeting behavior that obviously affect a multispecies fishery (Winker *et al.*, 2013)
3. think about the approach of (Thorson *et al.*, 2016) and how it could potentially be applied using the reference fleet data

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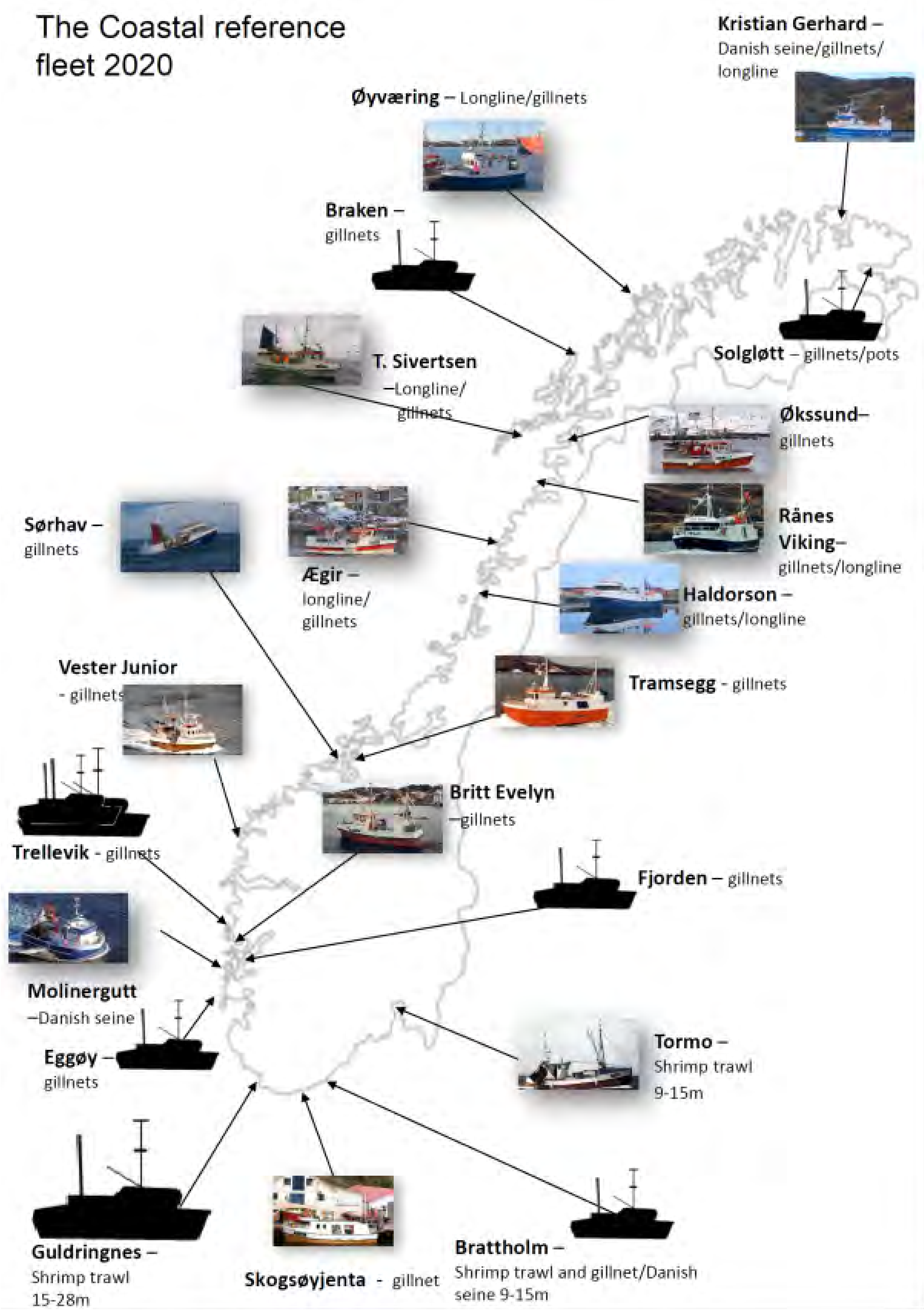
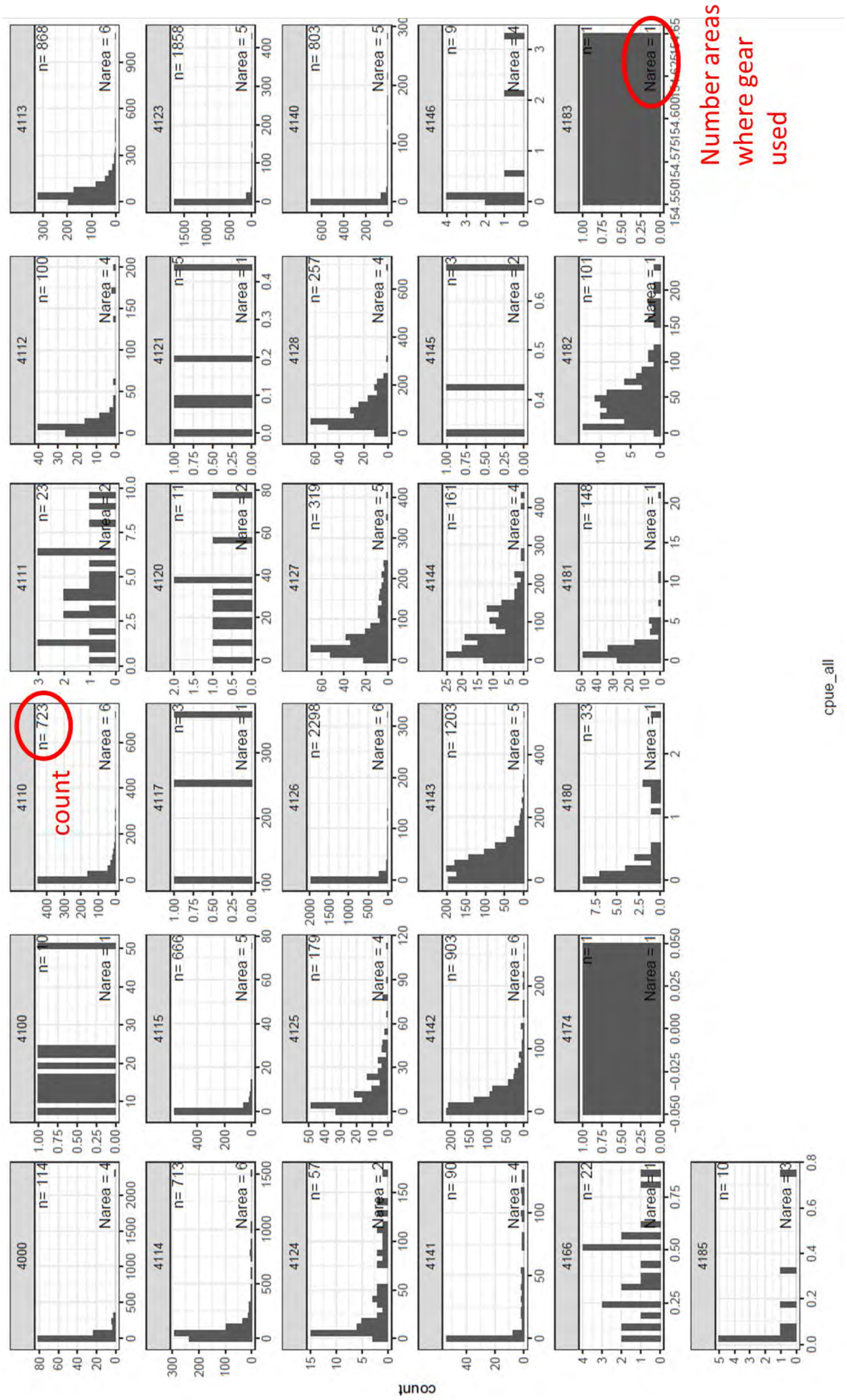
Appendix figure 1.



Appendix figure 2. GEAR type count and area usage.



Working document to the ICES benchmark workshop on Barents Sea and Faroese stocks (WKBarFar), 1-5 February 2021:

A state-space assessment model for Norwegian coastal cod north of 67°N

Johanna Fall

Institute of Marine Research, Bergen, Norway

2021-03-22

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1. Background

Cod (*Gadus morhua*) in the Barents and Norwegian Seas live under variable environmental conditions and differ in migration pattern, growth, maturation rates, and genetic markers. Two main stocks are recognised in these waters: the Norwegian coastal cod and the Northeast Arctic (NEA) cod. While their main distribution areas differ, both types of cod can be found together on spawning grounds during the spawning period, as well as in inshore and offshore catches all year round. Stock identity for ages 2+ is confirmed based on otolith shape, while younger fish cannot be reliably separated. There are genetic differences within the coastal cod stock as well, which is the basis for the 62°N cut-off to this population. In addition, there is a tendency for genetic differences between coastal cod south and north of Vesterålen (approximately 67°N, Dahle et al. 2018).

A large proportion of annual landings of coastal cod is taken as bycatch in the fishery for NEA cod. A part of the annual TAC for NEA cod is set aside for coastal cod (40 kt in the years 1987-2003, 20 kt in 2004, and 21kt in later years). A direct TAC for coastal cod cannot be implemented since it is not possible to visually separate fish from the two stocks. Several technical regulations have been introduced to reduce “bycatch” of coastal cod; year-round gear restrictions and restrictions on vessel size inside defined fjord areas, and closures of some spawning areas in the spawning season. Coastal cod is currently managed according to a rebuilding plan established in 2011. However, fishing mortality has not been reduced in accordance with this plan.

An auxiliary assessment model has been run each year at the Arctic Fisheries Working Group. The model is a traditional Virtual Population Analysis model (VPA) combined with a trial Extended Survivor Analysis (XSA) that is used to estimate terminal F for the VPA (the XSA is considered relevant to historic trends only). The model includes data for the whole coast north of 62°N and have one tuning series (acoustic index) from the coastal survey.

The majority (80 %) of coastal cod catches are taken north of 67°N. This is also where the coastal survey has best coverage and genetic studies suggest a more homogenous subpopulation. Recent updates of the catch series, a revision of the acoustic index and a new swept area survey index have improved the data basis for assessment in the northern area. This document details the development of an analytic stock assessment model for coastal cod north of 67°N for the purpose of improving the basis for advice in this area. We choose the SAM (State-space Assessment Model) framework (Nielsen and Berg, 2014), which is the same framework used to assess Northeast Arctic cod.

2. Data input

The year range of the assessment presented here is 1994-2019. Revised catch data is available from 1994. The survey has run since 1995 in October-November each year, first as an acoustic survey only and since 2003 with fixed bottom trawl stations in addition to continuous acoustic registrations. Revision of catch data back to 1984 was not ready in time for the benchmark and will be presented for review at a later inter-benchmark or short review in connection with the Arctic Fisheries Working Group. If these data are approved, the model may be extended further back in time. The age range in the new assessment model is 2-10+ and Fbar is the average F for ages 4-7. Revised catch data, survey data, and methods and data for estimating natural mortality were approved at the WKBarFar data workshop in December 2020.

2.1. Catch numbers at age and mean weights in catch (Tables A3-A4)

The revised catch data (1994-2019, 2020 is not available until March 2021) include commercial catches and an estimate of recreational catches. The age range is 2-10, where 10 is a plus group. The weight at age in the plus group is calculated as mean weight of the ages included in the plus group, weighted by abundance at age. The estimate of recreational catch is a constant catch in tonnes added each year and split by age based on the age structure in the commercial catches. There is ongoing work to obtain annual estimates of recreational catch for later years. Details on the catch data revision is found in WD-7 and WD-13.

2.2. Assumptions on landings and discards

We assume that all fish caught commercially are landed, i.e., no discards, as discarding is banned in Norwegian waters. Some minor discards may occur, mainly in gill net fisheries, where occasionally scavengers reduce the catch quality (Berg, 2020). The recreational catches include estimates of discards (mainly from catch-and-release) for which the assumption is 20 % mortality.

2.3. Survey data and mean weights in stock (Tables A5-A8)

Two tuning series are available, one acoustic index (1995-2019) and one swept area index (2003-2019), calculated from the same survey - the Norwegian annual coastal survey in autumn (NOcoast-Aco-4Q). The acoustic index has been used in previous assessments of the entire coastal cod complex but was revised for the benchmark, while the swept area index is new (WD-14). In both indices, the age range is 2-10, where 10 is a plus group. Indices from 2020 are also available and will be used in the 2021 assessment. The two survey indices are not completely independent as trawl catches are a source of information in the allocation of acoustic backscatter to species and length distributions from trawls are used to split the acoustic backscatter by age. However, there are many areas along the coast that are only accessible with acoustic gear due to irregular topography. Further, acoustic registrations are made throughout the water column, while the trawl samples near-bottom distributions. In cases where pelagic acoustic registrations are allocated to cod, pelagic trawl hauls targeting the registrations are also used to split the acoustic backscatter on coastal cod and NEA cod, and the coastal cod by age. The indices therefore contain some independent information as well. At the data workshop, it was recommended to explore including one series as a total biomass index and the other as numbers at age, compared to having both indices disaggregated.

Stock weight at age 2-7 was taken from individual samples included in the acoustic index. These come from fixed bottom trawl hauls and pelagic/bottom trawl hauls set out on acoustic registrations. We use the acoustic series as it covers a longer time period. Weights for ages 8-10+ was set equal to weight at age in the catch due to few samples in survey data that gave unreasonably large variation between years. Weight at age in the stock in 1994, when we have catch data but no survey data, was for ages 2-7 set to the average weights at age in the survey in 1995-1997, and equal to the weight in catch for ages 8-10+.

Concerns were raised about using weight at age in the catch as weight of the oldest age groups in the stock, since most of the catch is taken in quarters 1 and 2 while the survey is in quarter 4. Catch weights by quarter was then examined, showing that catch weight decreases during the year (Fig. 1). This is probably caused by weight loss after spawning in combination with differences in fishing selectivity throughout the year. The official catch weight at age is a mean across the year weighted by catch numbers. Though this may slightly overestimate catch weight in quarter 4, the reduction in catch weight at age from Q1 to Q4 means that the overestimate is lower than expected. The catch weight at age 8 and 9 is also close to the survey weight for these ages, but with less noise (Fig. 1). For the plus group, catch weights are higher than survey weights, but the survey weights cannot be evaluated with confidence due to few samples. It was decided to use catch weights as weight in the stock for ages 8-10+.

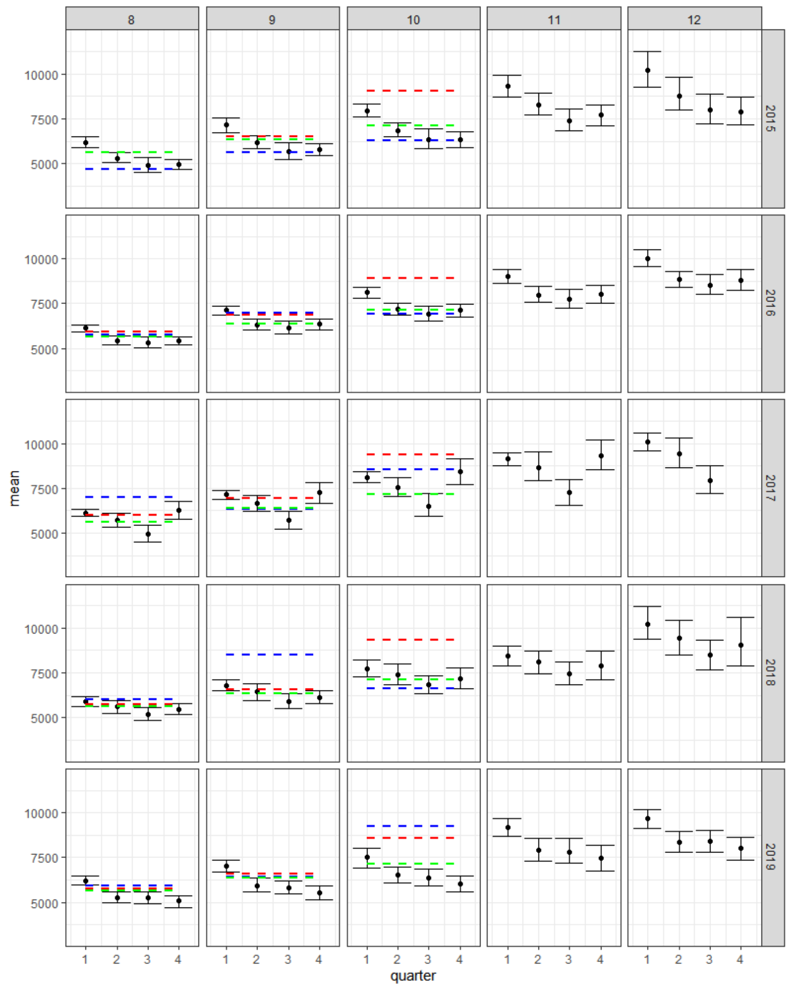


Figure 1: Weight at age in the catch for ages 8-12 (columns) in 2015-2019 (rows), estimated by quarter using the ECA software. The black points show the mean weight in each quarter with error bars showing 5-95 % quantiles. The red line is the mean weight in catch across the entire year, the blue line is the mean weight estimated from survey data in Q4, and the green line is the average weight in the survey for the years 2008-2019 when there was

more data on these ages. For age 10, the vertical lines show weight of the plus group (10+) and are therefore higher than the estimate for age 10 only.

2.4. Natural mortality (Table A9)

As there is no direct estimate of natural mortality available for this stock, three size-based estimates were proposed at the December data workshop (WD-18). These estimates are based on meta-analysis of several fish species with empirical estimates of natural mortality, relating M to body mass, body length, and/or growth parameters (Lorenzen 1996, Gislason 2010, and Charnov 2013). M-estimates from the December working document were recalculated for the main benchmark based on individual data from the longer acoustic data series. This resulted in an asymptotic length L_∞ = 96.8 cm, and growth parameter k = 0.205 (t_0 = -0.0389). The three different size-based Ms, varying between years according to changes in length/weight at age, were evaluated against a baseline mortality of 0.2 for all ages and years. In each M dataset, natural mortality at age in 1994 was set to the average M at age for the years 1995-1997.

2.5. Maturity ogive (Table A10)

The maturity ogive was calculated from survey data, using all individual samples from the acoustic index. Initially, the ogive was calculated in the same way as for NEA cod, where the proportion mature at age is the number of individuals in stage 2 (maturing) and 3 (running/spawning), divided by the sum of these individuals and the number of immature individuals. However, the resulting maturity ogive showed some erratic variation between years caused by sparse data for the oldest fish and extremely few observations of individuals of stage 2. This is not surprising since coastal cod spawn in March-June, while the survey data come from October-November. To get a more robust estimate of maturity at age, it was initially proposed to use a constant ogive calculated as the mean maturity at age over the entire time series. However, it was noted that a high number of individuals had been classified as stage 4 (spent or resting, Table 1), suggesting that at the time of the survey many mature individuals had not yet started to mature their gonads for the coming spawning season. An alternative mature ogive was therefore calculated where stage 4 was included in the mature fraction. This ogive was validated against data from the coastal reference fleet (2008-2020). While these data were relatively sparse (Table 2), they included information on maturity in quarters 1 and 2, i.e., around the time of spawning. The maturity ogive calculated from survey data including stage 4 was similar to the ogives calculated in the conventional way (not including stage 4) from reference fleet data for quarters 1 and 2 (Fig. 2). We therefore consider the former our best estimate of maturity at age for this stock. Further, including stage 4 gave clearer trends in maturity over time, with less noise (Figs 2 and 3). At the benchmark, it was decided to include stage 4 in the maturity ogive and to use annual values.

Table 1: Number of sampled individuals by maturity stage in the acoustic index 1995-2019. Stages highlighted in green are those considered mature in the maturity calculation for Northeast Arctic cod, while for coastal cod, spent individuals (highlighted in pink) are also included as mature due to the timing of the survey.

Year/ Stage	Not registered **-**	Immature **1**	Maturing **2**	Spawning **3**	Spent **4**	Uncertain **5**
1995	0	923	4	0	528	3
1996	7	904	124	0	460	2
1997	31	709	263	0	92	10
1998	9	1285	431	2	41	18
1999	0	1373	398	4	44	4
2000	7	2232	404	7	333	16
2001	11	1238	300	0	452	11
2002	1	732	308	0	187	10
2003	0	1250	269	0	496	25
2004	2	706	178	1	268	13
2005	1	442	213	0	81	13
2006	0	438	334	1	126	6
2007	1	258	214	0	90	0
2008	0	602	343	0	87	10
2009	0	827	243	0	125	8
2010	15	831	182	0	347	23
2011	2	764	285	0	171	25
2012	0	793	106	1	314	79
2013	2	859	319	0	267	31
2014	0	1046	175	0	518	84
2015	2	1017	77	1	347	95
2016	4	1277	62	0	518	36
2017	1	928	146	0	315	51
2018	248	919	139	0	322	65
2019	2	1051	218	4	341	37

Table 2: Data on maturity at age from the coastal reference fleet 2008-2020. The table shows the number of samples by age and maturation stage. The samples were taken in quarter 1 (2538 samples), quarter 2 (747 samples), quarter 3 (58 samples) and quarter 4 (154 samples).

Age/ Maturation stage	**1**	**2**	**3**	**4**	**5**
2	1	0	0	0	0
3	38	4	0	9	3
4	161	136	17	47	61
5	198	395	77	53	139
6	137	492	154	52	80
7	47	360	136	52	36
8	24	191	75	18	25
9	8	91	39	7	9
10	3	48	21	8	5
11	4	25	8	3	0

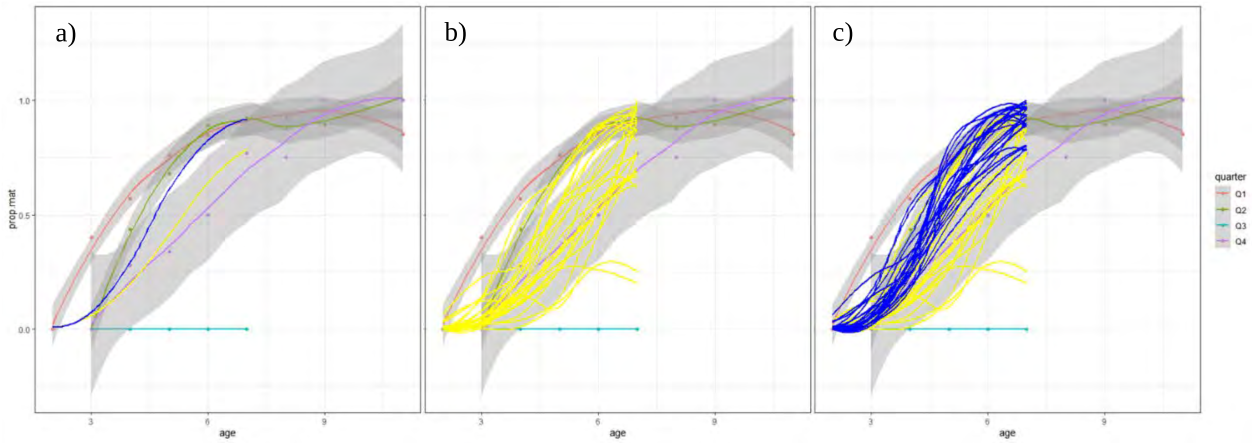


Figure 2: Maturity ogive by quarter estimated from reference fleet data (fishery-dependent data). In a) the lines with associated uncertainty intervals show ogives by quarter (colour), estimated in the conventional way (including stage 2 and 3 as mature). There were too few samples in Q3 to get a reliable estimate. The yellow line in a) and multiple yellow lines in b) and c) show the corresponding average and annual ogives estimated from survey data collected in quarter 4. Blue lines in panels a) and c) are average and annual ogives estimated from survey data, where stage 4 (spent) was also included as mature.

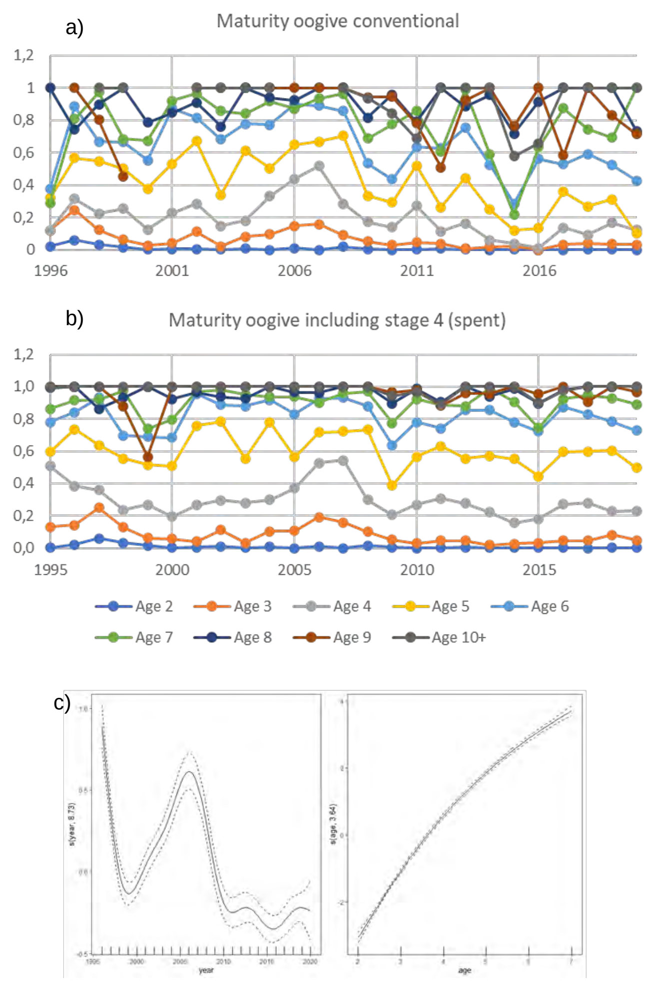


Figure 3: Maturity ogives estimated from quarter 4 survey data; a) with stages 2 and 3 defined as mature, and b) with stages 2-4 as mature. c) Trend in proportion mature over time and by age estimated from a binomial Generalised Additive model of mature/not mature against smoothers of year and age. The year and age trends were significant; year: edf = 8.7, p < .001, age: edf = 3.6, p < .001 and the model explained 38.5 % of the deviance.

2.6. Proportion F and M before spawning (Tables A11-A12)

These proportions were set to 0.8, representing the time of the year corresponding to the middle of the survey. With this setting, 80 % of the annual F and M are applied before calculating SSB. While the cod spawns in spring, we shift the spawning to late October (approximately October 20) in the model since the data on weight in the stock and maturity ogive comes from this time of year. This should not be a problem for management as long as reference points and the future management plan/harvest control rule consistently relate to SSB in late October.

3. SAM settings and candidate models

3.1. Modelling approach

The approach to find a new assessment model consisted of three parts:

1. Find best data input (evaluate different options for tuning series and natural mortality)
2. For the best data input, find the best SAM configuration
3. Validate the model

In some cases, steps 1 and 2 were considered iteratively, as certain configurations (settings) in SAM could improve the fit to a particular dataset.

The internal configurations in SAM was initially set to default values, and other configurations were compared to the default. While the default configuration is by no means a ‘standard’ to go after, it gives us a baseline to work from as we had no previous SAM to compare with. The default configuration has the following settings:

- Fishing mortalities for last two ages, i.e., age 9 and 10+, are coupled (assumed to be identical)
- AR-correlation of F across ages
- Survey catchabilities for last two ages are coupled
- Constant variance in the logF-process

- Separate variance for first age in the logN-process, other ages coupled
- Constant observation variance across ages in catch and in each survey
- No correlation structure between ages in the surveys
- Recruitment is modelled as random walk

The only initial change made to the default configuration was changing Fbar to ages 4-7, to match the previous VPA settings.

3.2. Data options

The following data input options were considered:

- Tuning series – numbers at age vs total biomass index (TSB)
    a. Acoustic index as numbers at age, swept area index as TSB
    b. Acoustic index as TSB, swept area index as numbers at age
    c. Both indices as numbers at age
- Natural mortality
    i. Constant 0.2
    ii. Lorenzen (weight-based)
    iii. Charnov (length-based)
    iv. Gislason (length-based)

To find the best option for tuning series, models were run with SAM default configuration (except where it was necessary to change it to specify the use of a TSB index) and baseline natural mortality (i). To find the best option for natural mortality, models were run with SAM default configuration and data option (c) above. Different data inputs were compared based on residual and retrospective patterns. Log likelihood/AIC cannot be compared when models have different data inputs. An attempt was made to adjust AIC values for the additional number of parameters introduced (from outside the model) when including a size-based M. However, this

AIC should be considered approximate as the additional parameter(s) are not included in the model itself.

3.3. Configurations

Configurations were evaluated in the following order:

1. Coupling of fishing mortalities
2. Coupling of survey catchabilities
3. Coupling of observation variances
4. Correlation between ages in observations

Each configuration was evaluated separately, e.g., different options for coupling of Fs were tried while the rest of the configuration was kept at default. To find the optimal configuration, the model was fit as freely as possible, i.e., each age was given its own parameter. The fit was then evaluated to see if certain ages had similar parameter estimates and could be coupled. New run(s) were made with coupled parameters and the default, free, and coupled configurations were compared by means of AIC, residual and retrospective patterns (Mohn's rho in combination with visual inspection of retrospective peels).

Finally, the best configuration for each step 1-4 above was put together in one model and evaluated.

4. Results

4.1. Data input

4.1.1. Tuning series

The baseline run, with swept area and acoustic survey indices as numbers at age, constant M = 0.2 and default configuration (option a), converged and showed one peak of SSB around 1995 and another in 2014-2015, but with lower recruitment for the same SSB in the latter period (Fig. 4). Note that after the benchmark, an error in the index calculation was found. This resulted in approximately 5 % lower model estimates of SSB but had small impacts on model fit. Therefore, only the final model figures, prediction and reference points (starting at section 4.3) have been updated in the step-by-step fitting process below. Appendix tables with survey data have also been updated.

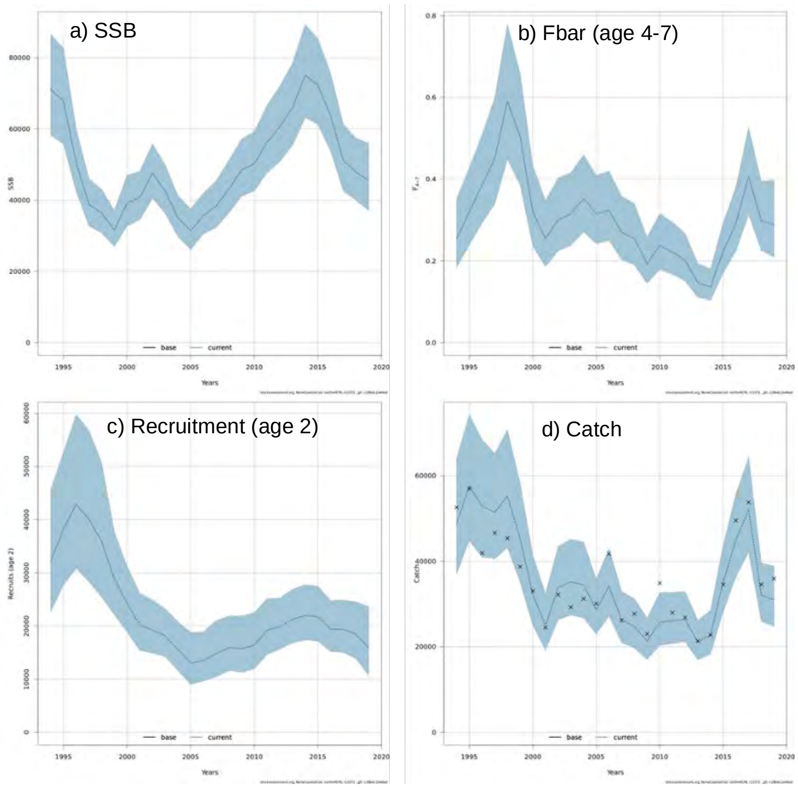


Figure 4: Output from SAM baseline run.

It was noted that the one-step-ahead residuals contained some annual patterns. There was also a cluster of negative logN process residuals. Leave-fleet-out runs showed the largest change in SSB, Fbar and recruitment estimates when leaving out the longer acoustic index, which substantially reduced the estimate of recruitment in the early period. The model did not have any concerning retrospective patterns (Mohn's rho SSB = -0.04, Fbar = 0.09, and recruitment = 0.01).

Including the acoustic index as TSB (option b) reduced the recruitment estimate at the beginning of the time series, supporting the view that the age information in the acoustic index was a strong driver of this estimate. A retrospective run of option b revealed bad retrospective patterns on both SSB and recruitment.

Including the swept area index as TSB (option a) surprisingly also reduced the early recruitment estimate somewhat and increased SSB (and thus reduced F) in the most recent years. The retrospectives on SSB and recruitment were worse compared to the baseline, but not as bad as for acoustic index TSB. Leave-fleet-out runs showed that the swept area TSB index contributed very little to the model. Including the swept area index as numbers at age revealed that the catchability was lower for ages 2 and 3. Therefore, aggregating the index overestimated catchability for the youngest age and underestimated it for the older ages.

The fits to acoustic and swept area TSB indices were generally poor and TSB indices did not remove residual patterns. It was decided to include age information in both indices.

In the process of evaluating the tuning indices, it was noted that the observed pattern in logN process residuals (Fig. 5) coincided with a known change in the survey design; before 2003, the coastal survey was a purely acoustic survey where trawling was performed on acoustic registrations only. From 2003, fixed bottom trawl stations were introduced. In the model run using acoustic TSB, the residual pattern was less prominent, suggesting that the pattern was related to age information in the acoustic index. To check if a change in catchability was the cause of the residual pattern, the acoustic index was split in two (1995-2002, 2003-2019), the model rerun, and catchability estimates compared with the run using the full index. It was clear that catchability had changed; both its level and the relative catchability at age (Fig. 6).

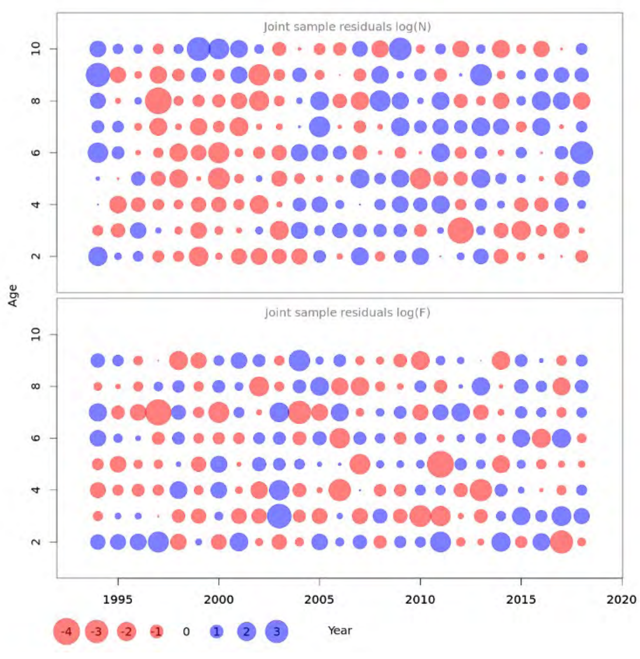


Figure 5: Process residuals for log(N) and log(F) from the SAM baseline run.

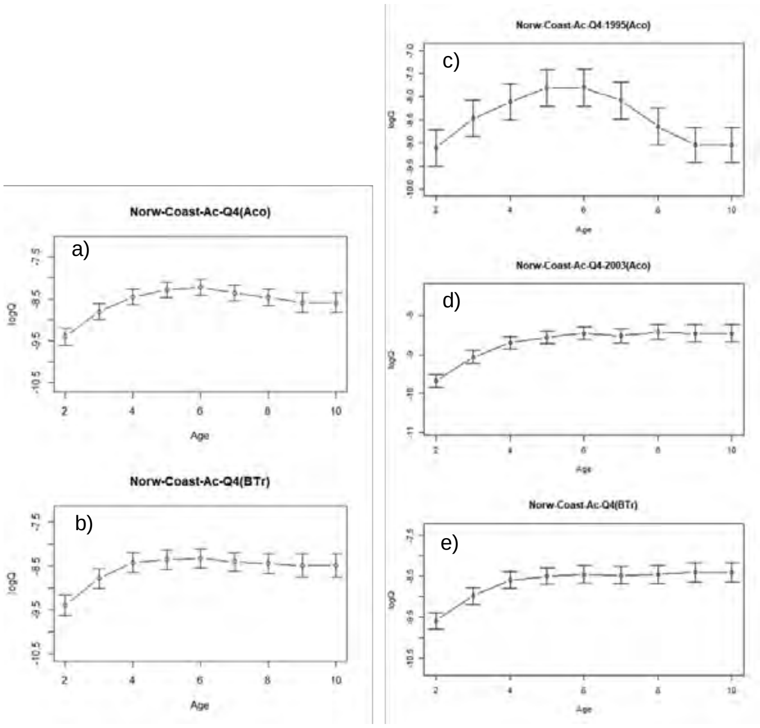


Figure 6: Estimated catchability at age from SAM runs with full acoustic index (left; a – acoustic index, b – swept area index) and split acoustic index (right, c – first part of acoustic index, d – second part of acoustic index, e – swept area index).

Compared to the full acoustic index, the split index gave lower SSB in the first part of the time series and higher in the second (Fig. 7). The first half of the acoustic index thus appeared to influence on current estimates of SSB when the index was included in its entirety.

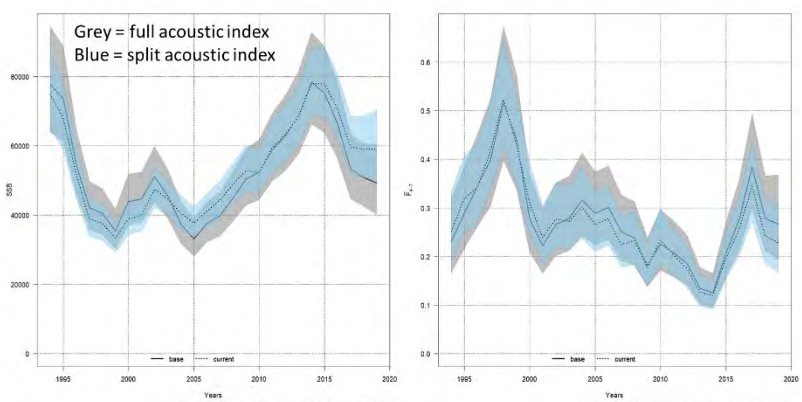


Figure 7: Estimates of SSB (left) and Fbar (right) from models with full and split acoustic index. Grey = baseline run with full acoustic index, blue = run with split acoustic index.

Splitting the index improved the process residuals (Fig. 8). Since the longest tuning series was substantially shortened by splitting, the retrospective pattern of the model with split acoustic index was a bit worse. However, this mainly affected recruitment. <u>It was decided to split the acoustic index to improve the process residuals and the potential over/underestimate of SSB due to changes in catchability</u>.

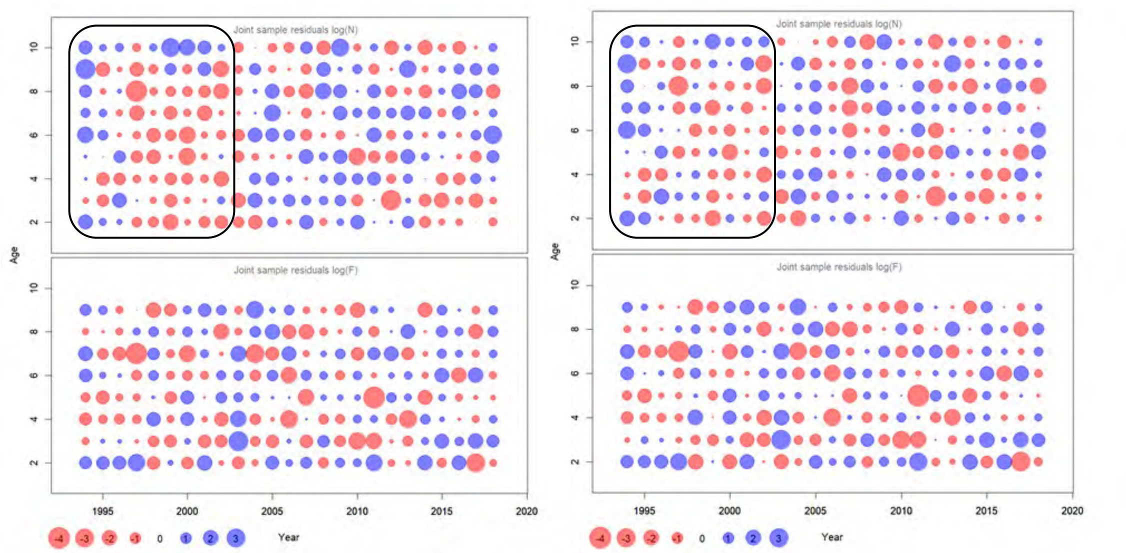


Figure 8: Process residuals from run with whole acoustic index (left) and split acoustic index (right). The residual pattern caused by changes in catchability in the acoustic index is circled in black.

4.1.2. Natural mortality

The size-based natural mortality tended to decrease over time since weight and length at age increased (Fig. 9). The model had to use a bit more process error in the fitting when including annual size-based Ms, but the fit to survey data was slightly improved for the youngest ages. A size-based M did not have any noteworthy influence on retrospective patterns or residuals. The AIC was slightly higher for models with size-based M compared to constant 0.2, but the difference was too small to support one method over another (Table 3). The model compensated for higher natural mortality by estimating lower catchabilities, substantially higher recruitment and somewhat lower SSB. Differences between the three size-based Ms were small (Table 3). It was discussed at the benchmark that Gislason M may give unrealistically low M for the oldest ages. For the southern coastal cod stock, simulations of an unexploited stock with Gislason M suggested an extremely high number of old fish compared to the observed length composition in the exploited stock. But as no unexploited cod stock exists today, the realism of this cannot be evaluated. Lorenzen M was favoured by the scientist working on the southern coastal cod stock – the M at age curve was similar in shape to that of NEA cod, but at a somewhat higher level, which fits given that the NEA cod estimate is based on cannibalism only. At the other end, Lorenzen gave lower estimates than those used in the North Sea cod assessment, where natural mortality is estimated in a multispecies model and the mortality curve is known to be steeper. In the end it was decided to balance the need for biological realism against potentially unrealistic estimates, and the weight-based Lorenzen M was chosen.

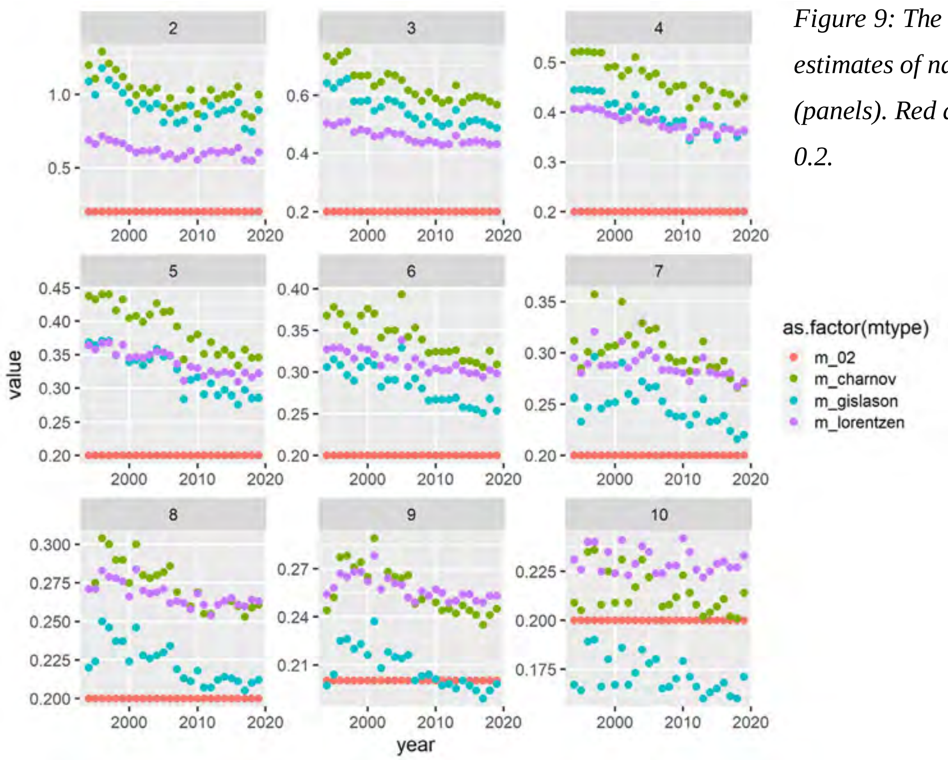


Figure 9: The three candidate size-based estimates of natural mortality by age (panels). Red dots illustrate constant M = 0.2.

Table 3: Estimated AIC for model runs with different natural mortality. The AIC was approximated from the log-likelihood by adding the extra number of parameters introduced from outside the model (two each for Charnov and Gislason, none for Lorenzen; AIC = 2(df + number of extra parameters) - 2*(log-likelihood)).*

M	AIC (adjusted for N par)
0.2	801.7
Lorenzen	805.3
Charnov	808.7
Gislason	804.3

4.2. Configurations

4.2.1. Coupling fishing mortalities (keyFsta)

Allowing separate Fs also for the last two ages gave much higher estimates of fishing mortality for age 10+ compared to age 9 (Fig. 10). Fs for ages 7-9 were similar and coupling these gave lower AIC compared to the default (coupling ages 9 and 10+) and the free configuration. The effect of this change on model output was small, but it gave lower SSB estimates with smaller confidence intervals in the first years, and a somewhat better fit to catch data (Fig. 11). It was agreed to couple F for ages 7-9 and give the other ages separate parameters.

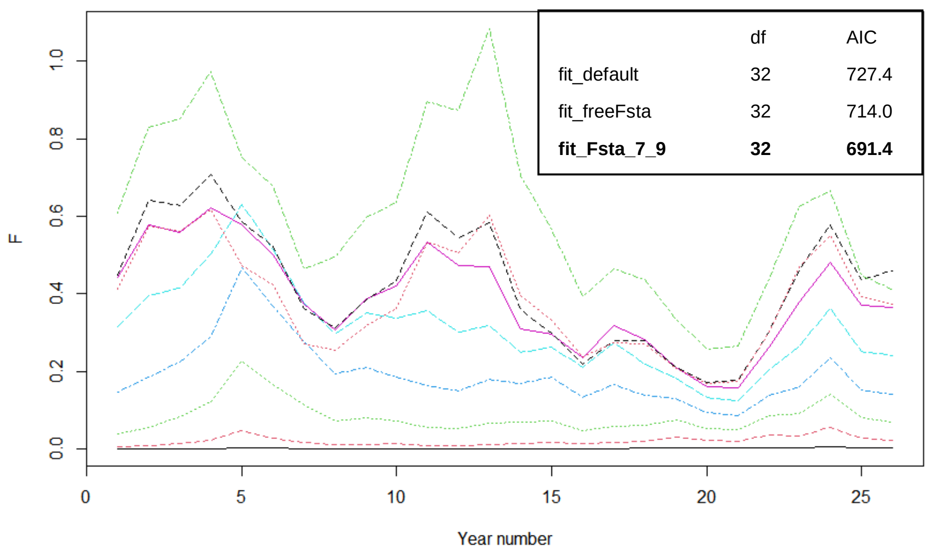


Figure 10: Estimated fishing mortality by age and year from a model with separate parameters for each age. Each age has a different colour/line type where the solid black line is age 2 and the dashed green line is age 10+.

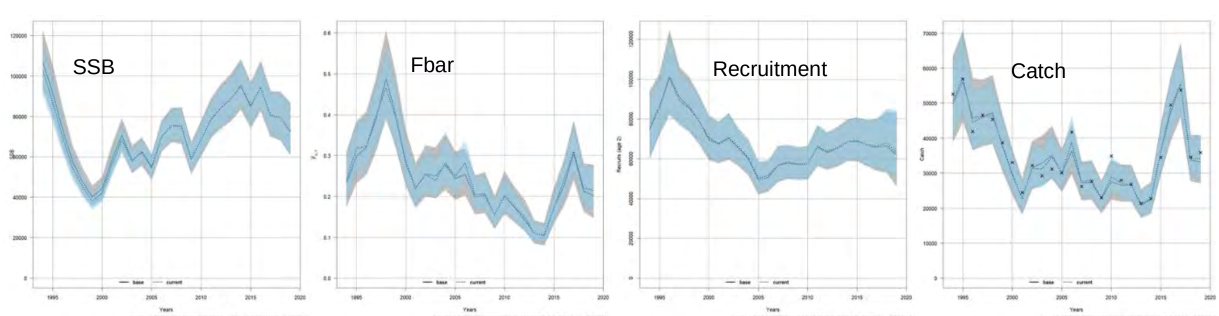


Figure 11: Effect of coupling F at age 7-9. Grey = default configuration (same F for age 9 and 10+, separate for other ages), blue = best configuration; coupling of F 7-9.

4.2.2. Coupling catchabilities (keyFpar)

The default configuration with coupled catchabilities for the last two ages was not a good fit according to the free estimate (Fig. 12). Catchability was dome-shaped in the first part of the acoustic index, while there was a plateau for ages 5-9 in the second acoustic and swept area indices. In all indices, plus group catchability was lower than catchability of age 9. Coupling catchabilities according to figure 12 gave lower AIC compared to the default and free configurations. The effect was a general increase in SSB, due to more accurate estimation of catchability for the oldest ages, and subsequent in adjustments to Fbar and recruitment (Fig. 13). It was agreed to use this coupling.

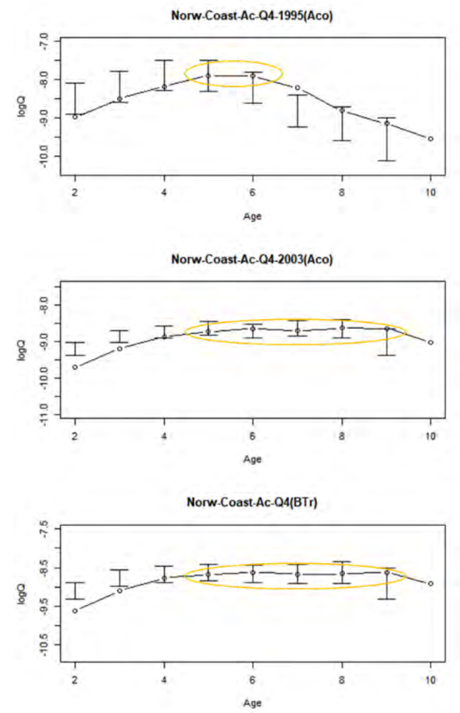


Figure 12: Estimates of survey catchability at age from a model with separate parameters for each age in each survey (top: acoustic 1995-2002, middle: acoustic 2003-2019, bottom: swept area 2003-2019). The estimates circled in yellow were similar and were subsequently coupled.

	df	AIC
fit_default	32	727.4
fit_Fpar_free	35	723.2
fit_Fpar_coupled	**26**	**707.0**

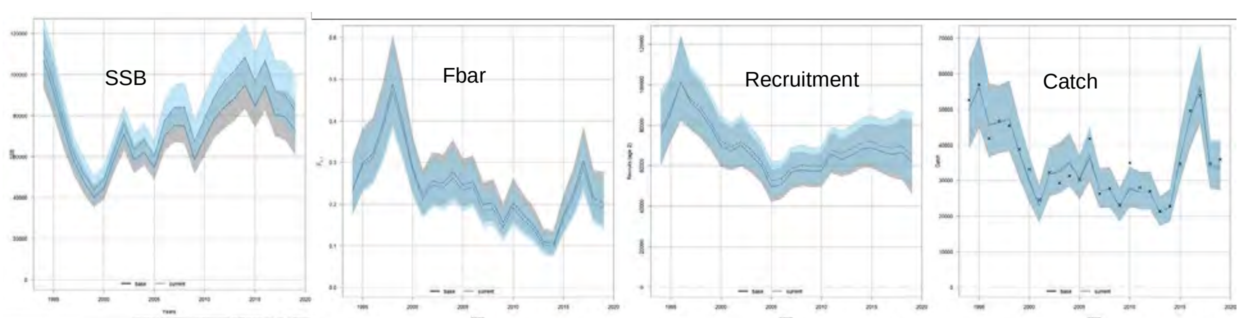


Figure 13: Effect of coupling survey catchabilities. Grey = default configuration (same catchability for ages 9 and 10+, separate for other ages), blue = best configuration; coupling according to figure 12.

4.2.3. Coupling observation variances (keyVarObs)

There were no clear indications that the default configuration of constant variance between ages was inadequate, except for larger one-step-ahead residuals for age 2 in the catch. Other common configurations were nevertheless tested, such as separate variances for youngest and oldest ages in catch and surveys (did not converge), separate variances for youngest age in catch and surveys (lower AIC but worse retro), separate variance for oldest age only (increased the AIC). Only the option of separate variance for age 2 in the catch improved fit, giving a much lower AIC compared to constant variance for all ages. The effect was a small upwards revision of SSB and much better fit to catch data (Fig. 14). <u>It was agreed to have separate variance for age 2 in the catch, and constant variance across ages in the surveys.</u>

	df	AIC
fit_default	32	727.4
fit_ age2_catchandsurvey	36	647.4
fit_pg_catchandsurvey	36	732.3
fit_age2_catchonly	**33**	**643.0**

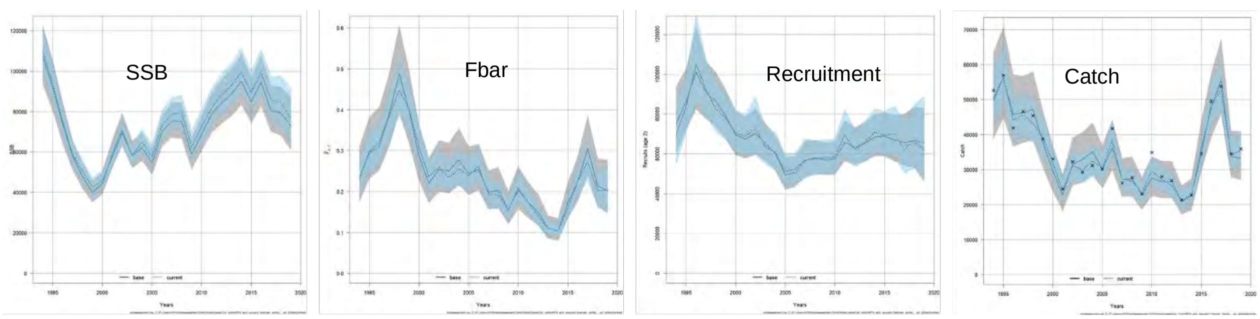


Figure 14: Effect of giving separate observation variance to age 2 in the catch. Grey = default configuration (constant variance for all ages), blue = best configuration; separate variance for age 2.

4.2.4. Correlation structures (keyCorObs)

Here the default is no correlation between ages. AR-correlation was explored by fitting a model with separate correlation parameters for each age pair in each survey (age 2-3, 3-4, 4-5, etc.). The model did not converge when this correlation was implemented for the acoustic index part 1, so correlation structures were further explored for acoustic part 2 and swept area index only. The correlation plot indicated that age pairs 5-6 and 6-7 in the acoustic index could be coupled (Fig. 15). In the swept area index, age pairs 3-4, 4-5, 5-6 could be coupled, and a separate coupling was indicated for ages 7-8, 8-9 and 9-10+ (Fig. 15). Correlation between ages imply that the model derives less information from the single age groups included in a correlated pair. This results in wider confidence bands on SSB and recruitment (Fig. 16). The model with correlation structure predicts higher recruitment in the first and last part of the time series compared to a model without correlations (Fig. 16). The AIC was substantially reduced when including correlation, and the annual patterns in the one-step-ahead swept area index residuals were removed (Fig. 17 a-b). There was less correlation to account for in the acoustic index and including correlation there gave a small, but not very concerning, pattern in the logN process residuals for age 3 (Fig. 17 c-d). However, not including correlation in the acoustic index gave a poorer retrospective pattern on SSB and Fbar (but improved the retro on recruitment). It was decided to include correlation structure in both survey indices according to figure 15.

Figure 16: Correlation plot from SAM run with AR correlation between ages, where each age pair was given a separate correlation parameter. The size of the bubbles are proportional to the estimated correlation parameters. Age pairs circled in yellow were coupled based on similar parameter estimates.

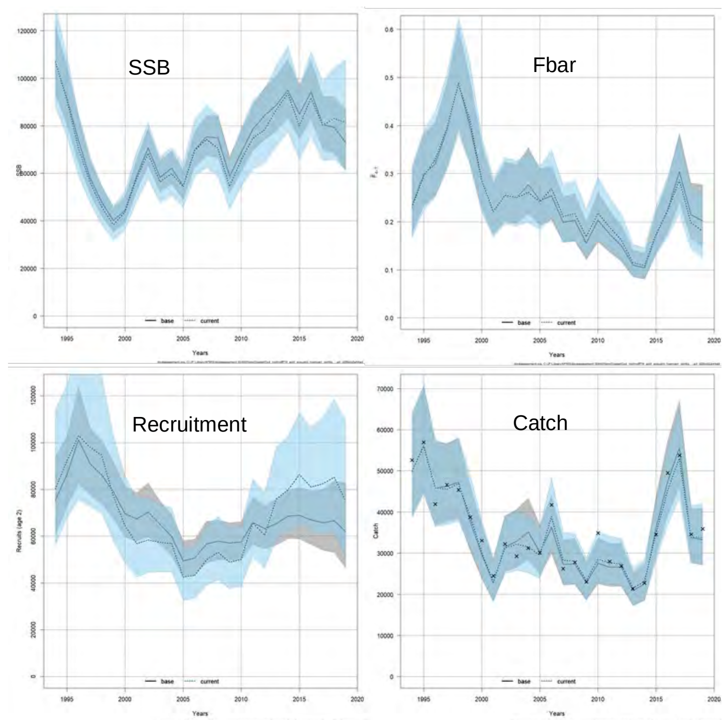


Figure 15: Effect of introducing correlation between ages in the surveys. Grey = default configuration no correlation), blue = best configuration; age pairs coupled according to figure 15.

	df	AIC
fit_default	32	727.4
fit_corr_free	48	562.1
fit_corrplot	**42**	**550.6**

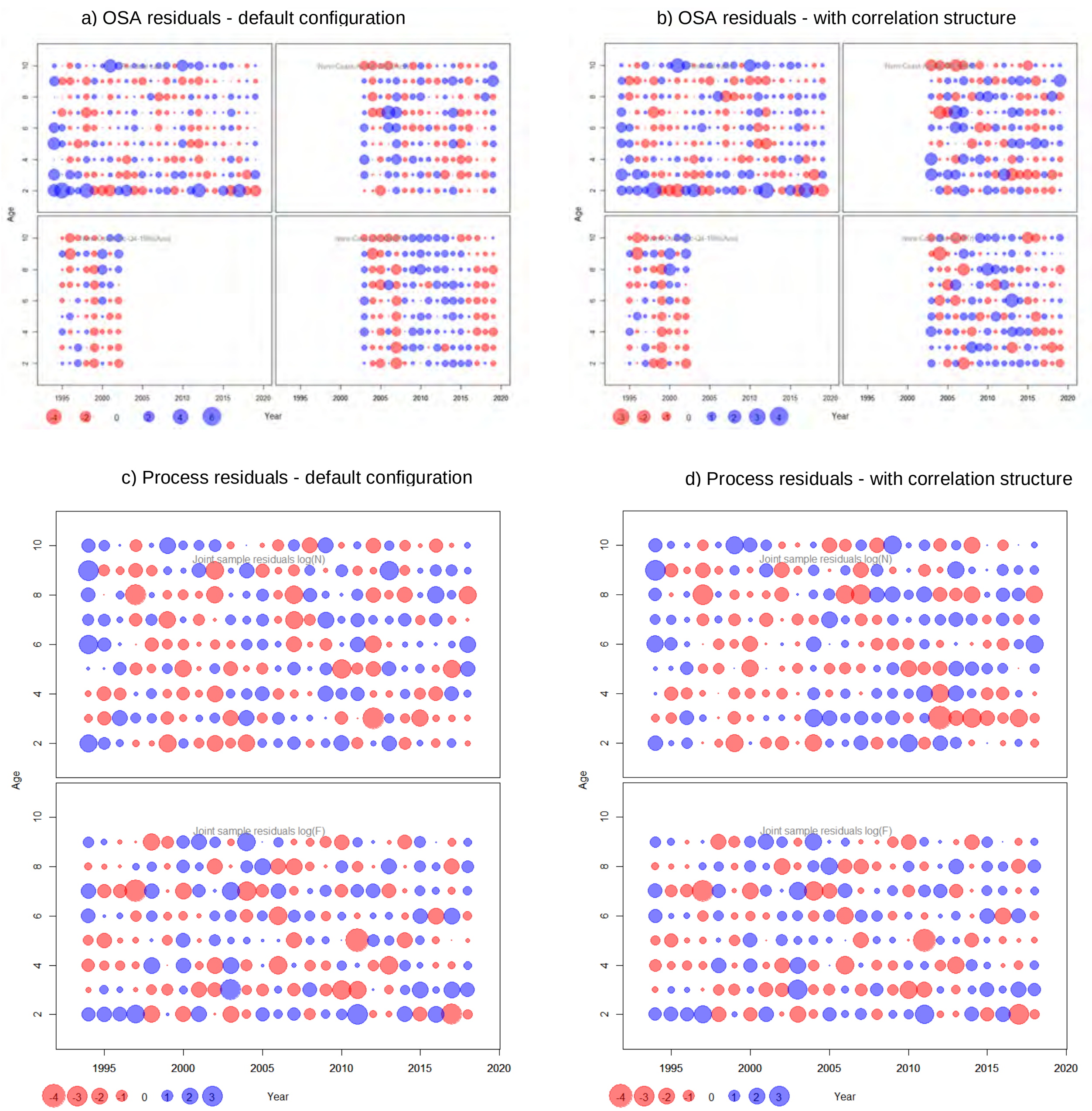


Figure 17: One-step ahead residuals for model with a) default configuration and b) correlation structure. log(N) (top) and log(F) (bottom) process residuals for model with c) default configuration and d) correlation structure.

4.3. Combining the best configurations

Applying all the changes to the configuration described above lowered the AIC from 727.4 (for default configuration) to 417.3, with the strongest reduction caused by introducing correlation structure. This is the final model approved by the benchmark meeting. The output is shown in figure 18 and tables A1-A2, and the configuration is presented in Appendix 3. The model can be found on stockassessment.org under the name NorCoastCodNorth_benchmark2021.

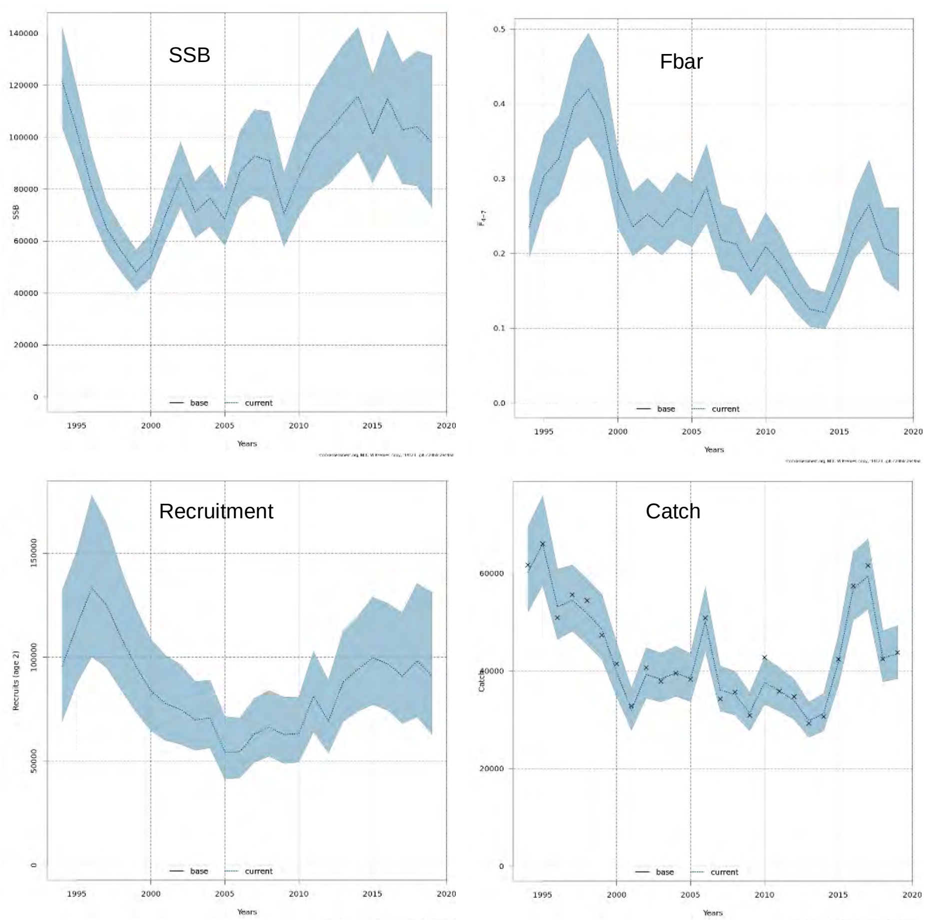


Figure 18: Output from final model run.

4.3.1. Model evaluation

4.3.1.1. One-step-ahead and process residuals

Residuals are presented in figure 19.

Figure 19: One-step-ahead residuals (top) and process residuals (bottom) from the final model.

4.3.1.2. Retrospective run

The retro on SSB shows some underestimation in the years up to 2012 and some overestimation in the following years, while in later years, estimates are close to the final run (Fig. 20). The largest uncertainty is observed for recruitment.

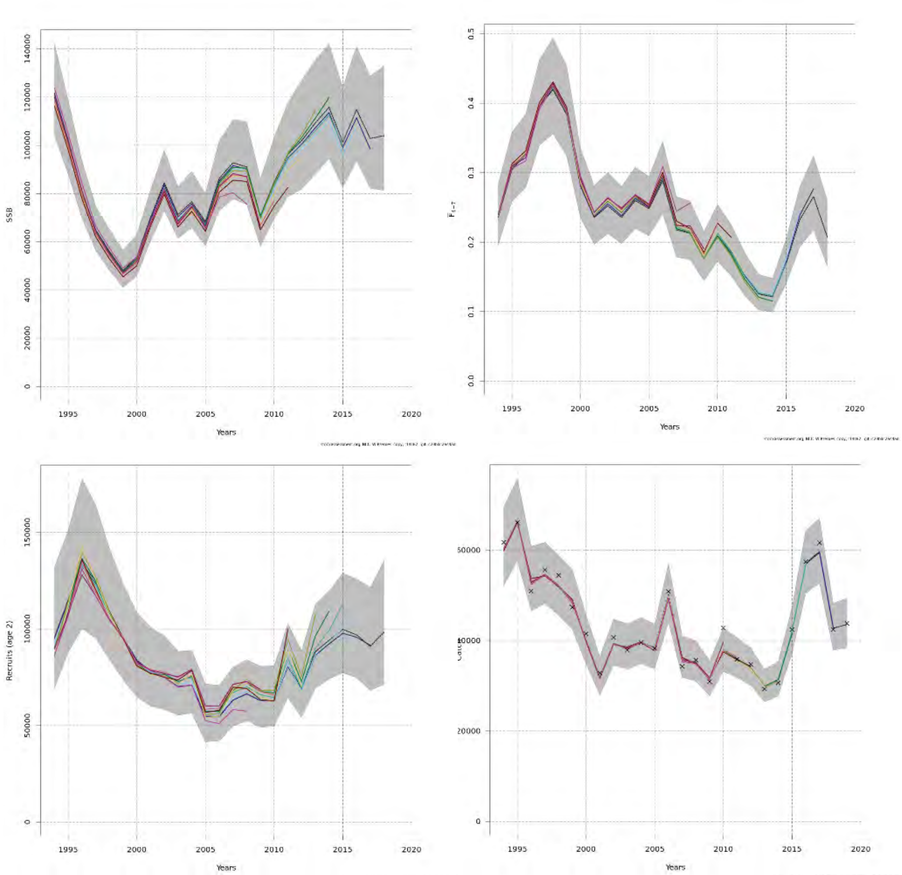


Figure 20: 10-year retrospective peel from final model. Mohn's rho (5-year retrospective bias) on SSB: 0.01, Fbar: -0.009, recruitment: 0.22.

4.3.1.3. Leave-fleet-out run

Leaving out the acoustic index part 1 has a small effect, though it appears to pull the estimate of SSB slightly downwards even in the last years (Fig. 21). Leaving out the acoustic part 2 has a similar effect as leaving out the swept area index; an increase in SSB particularly in later years with high biomass.

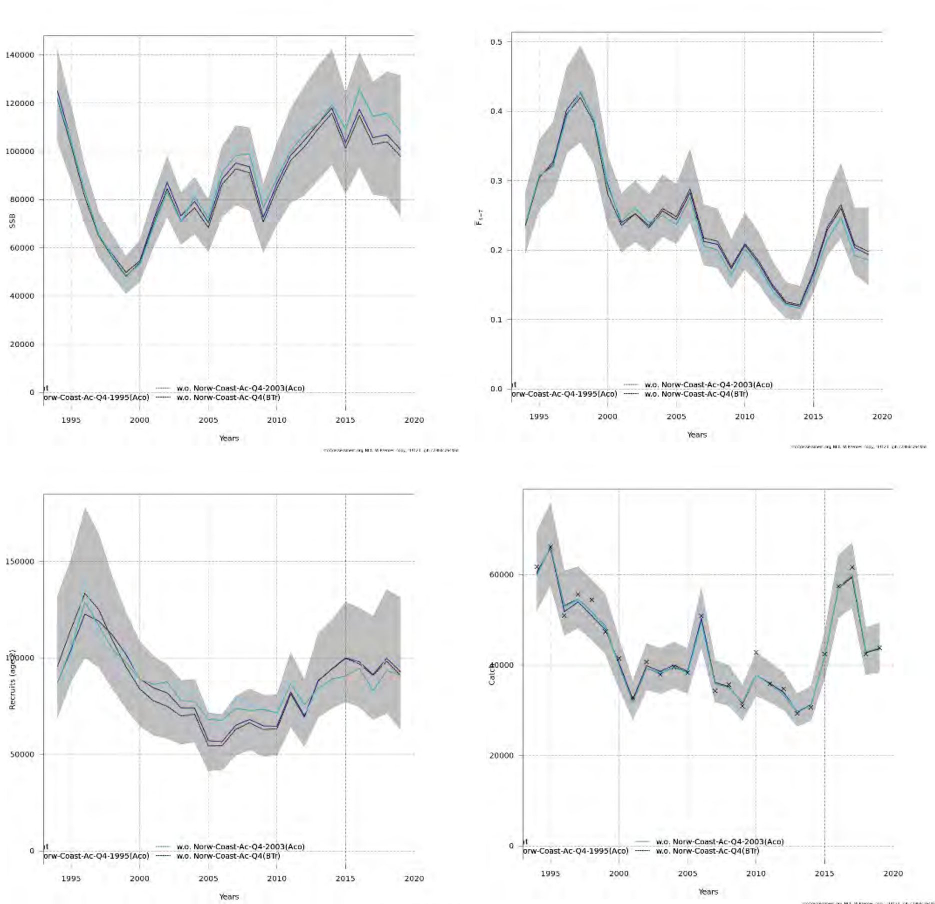


Figure 21: Leave-fleet-out run for the final model. Dark blue = leaving out acoustic index part 1, light blue = leaving out acoustic index part 2, green = leaving out swept area index.

4.3.1.4. Jittered starting points analysis

In the jitter analysis the model is rerun with the initial values widely scattered in order to check that the model is robust enough to obtain similar parameter estimates. Our final model gave deviations well within acceptable limits (Table 4, deviations at the 4th or 5th decimal may be concerning).

Table 4: Maximum deviations in parameter estimates obtained in a jitter analysis with 10 iterations.

Parameter	max(|delta|)
logFpar	1.21E-11
logSdLogFsta	5.01E-13
logSdLogN	1.03E-12
logSdLogObs	1.62E-12
transfIRARdist	1.18E-11
itrans_rho	1.10E-12
logF	1.63E-10
logN	1.28E-10
ssb	1.10E-06
fbar	4.51E-12
rec	2.05E-06
catch	2.56E-07
LogLik	2.88E-10

4.3.1.5. Simulation validation

The simulation validation is a parametric bootstrap of the model (self-test) where input data is simulated and the model re-estimated. A simulation with 50 iterations gave acceptable results, with trajectories mainly within the confidence intervals of the model (Fig. 22). The main cause of variation in the trajectories was variation in parameters relating to the correlation structure (transfIRARdist, Fig. 23).

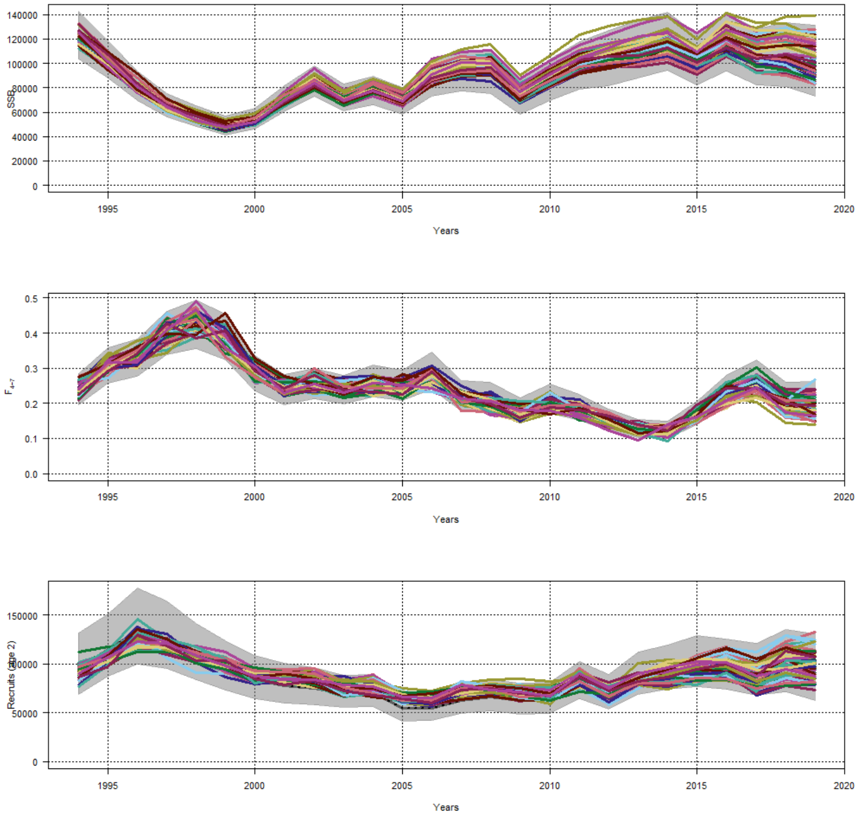


Figure 23: Results from simulation validation (50 iterations, coloured lines) of the final model. Top: SSB, middle: Fbar, bottom: recruits.

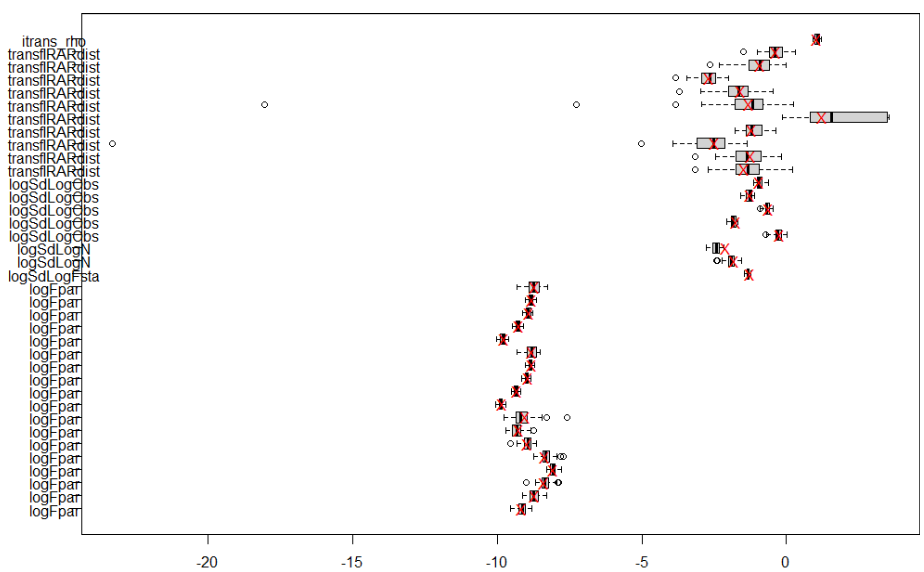


Figure 22: Variation in parameter estimates in the 50 simulations. Red crosses mark corresponding estimates in the final model.

4.4. Short-term forecast

The built-in forecast option in SAM was approved for use in short-term prediction. In the forecast, F was set to status quo (same as in the terminal year of the assessment; fscale=c(1,1,1,1)) and process noise was included (i.e., processNoiseF=FALSE). In the default forecast settings, averages from the last 5 years are used for stock weight, catch weight, and maturity at age, and recruitment is resampled from the last 10 years. These settings were used, but it was recommended by the benchmark to try a longer period from which to resample recruitment, e.g., from 2002 after which the stock-recruitment relationship had a less steep incline (see Fig. 25). It was agreed that this decision could be made by the stock assessors and was not further explored at the benchmark. The results presented here are from a forecast with 10-year resampling of recruitment. Under status quo, the model predicts a highly uncertain increase in SSB in the coming years (Fig. 24, Table 3).

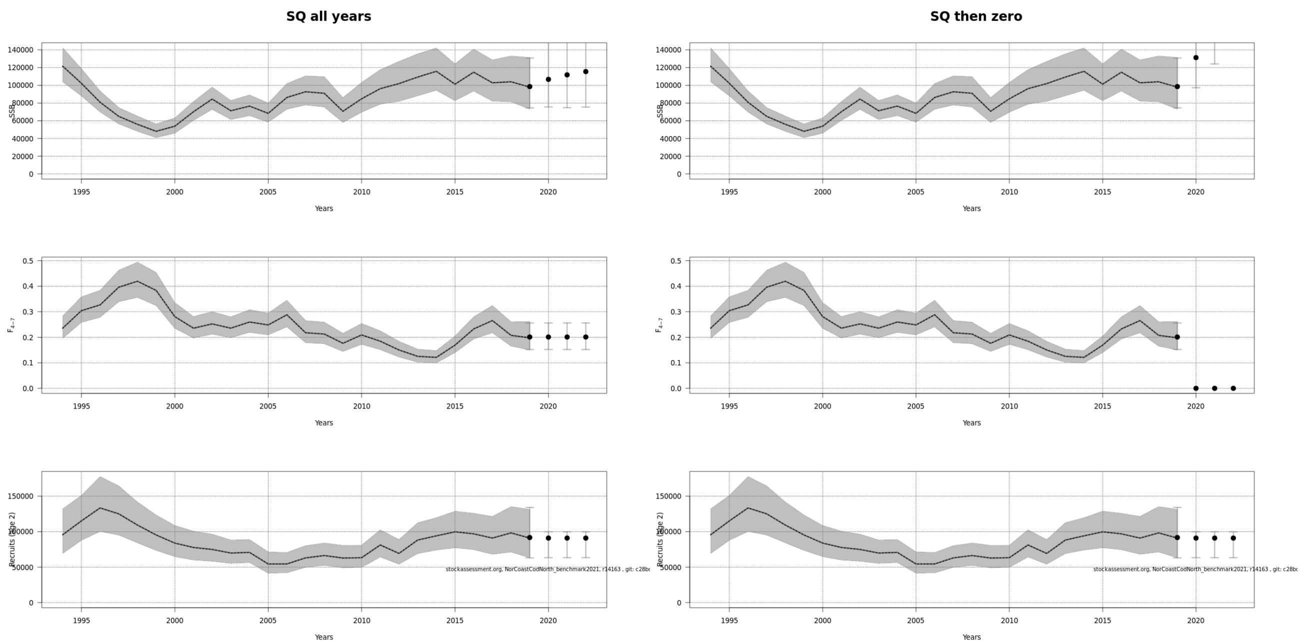


Figure 24: Three-year forecast from the final model. The left-hand panels show the official forecast that assume status quo F. To the right are predictions based on zero fishing.

Table 5: Forecast table including the terminal year of assessment (2019). Assuming same F as in terminal year.

Year	fbar: median	fbar: low	fbar: high	rec: median	rec: low	rec: high	ssb: median	ssb: low	ssb: high	catch: median	catch: low	catch: high
2019	**0.201**	0.152	0.256	**91742**	63043	134068	**98582**	74553	130727	**43654**	38768	49353
2020	**0.201**	0.152	0.256	**90956**	63324	99790	**106705**	75594	150043	**44895**	38356	52347
2021	**0.201**	0.152	0.256	**90967**	63324	99790	**111797**	74777	164843	**46700**	37992	57212
2022	**0.201**	0.152	0.256	**90956**	63324	99790	**115483**	75441	174399	**47636**	38515	59424

4.5. Reference points

The estimated stock-recruitment relationship generally showed an increase in recruitment (at age 2) with SSB. However, the stock appears to have followed different trajectories in the first 6-7 years of the time series compared to the years after; the same SSB yielded higher recruitment in the first period. The shape of the stock-recruitment relationship gives little indication that a plateau in recruitment has been reached within the time period considered, and consequently, SSB is likely below B_{lim}. However, with no apparent plateau, estimation of B_{lim} – and consequently, estimation of all other reference points – is highly uncertain. An attempt was

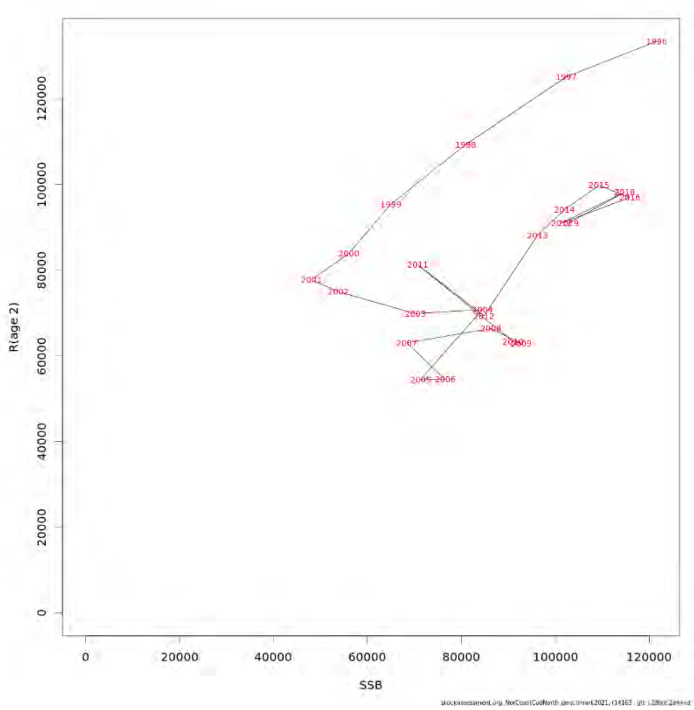


Figure 25: Stock-recruitment plot from SAM, where recruitment is a random walk process. Recruitment at age 2 is plotted against SSB estimated two years previously.

nevertheless made to estimate B_{lim} based on ICES guidelines.

The ICES guidelines on calculation of reference points starts with identification of stock type based on the stock-recruitment (S-R) relationship. There is naturally some variation around these idealised types, and none may be a perfect fit to a given stock. The benchmark agreed that the closest stock type to the estimated S-R relationship was Type 3. This is a stock with a wide range of SSB with evidence of impaired recruitment and no clear asymptote in recruitment at high SSB. It was argued that the stock shows evidence of impaired recruitment since recruitment increases with SSB over the range of values observed. Alternative stock types were discussed; Type 5 with no clear S-R relationship and Type 6 with a narrow range of SSB. But as those types are not supposed to show impaired recruitment, they were not considered appropriate.

For a Type 3 stock, B_{lim} may be close to the highest SSB observed, but evaluation of B_{lim} depends on an evaluation of historical fishing mortality and thus rely heavily on expert opinion. Due to the lack of a plateau and years with very low recruitment, a segmented regression was of little help in determining B_{lim}. Using EQSIM, a free segmented regression put B_{lim} at approximately 55000 t (Fig. 26 a), rather close to B_{loss}, which seems highly unlikely given the strong increase in recruitment with SSB after this point. Catches of coastal cod were high in the mid-1980s when the fishery along the Norwegian coast was practically unregulated, at least as high as in the first years of the assessment model. Introduction of strong regulations on the Northeast Arctic cod fishery in the 1990s followed by regulations on the coastal fishery in the early 2000s seem to be followed by increases in SSB and recruitment based on the SAM. Based on this reasoning, it was decided to place B_{lim} close to the highest SSB observed.

As the S-R relationship in the early part of the model followed its own (parallel) trajectory, possibly representing a different state of the stock or the ecosystem, we focused on the S-R relationship in the second part (2003-2017) and set B_{lim} to the highest observed SSB in this period (SSB_{2014} = 115782 t, shown as 2016 in Fig. 25). This is approximately 6000 t lower than the highest SSB in the first period (SSB_{1994} = 121547 t). A segmented regression based on the final B_{lim} is shown in figure 26 b.

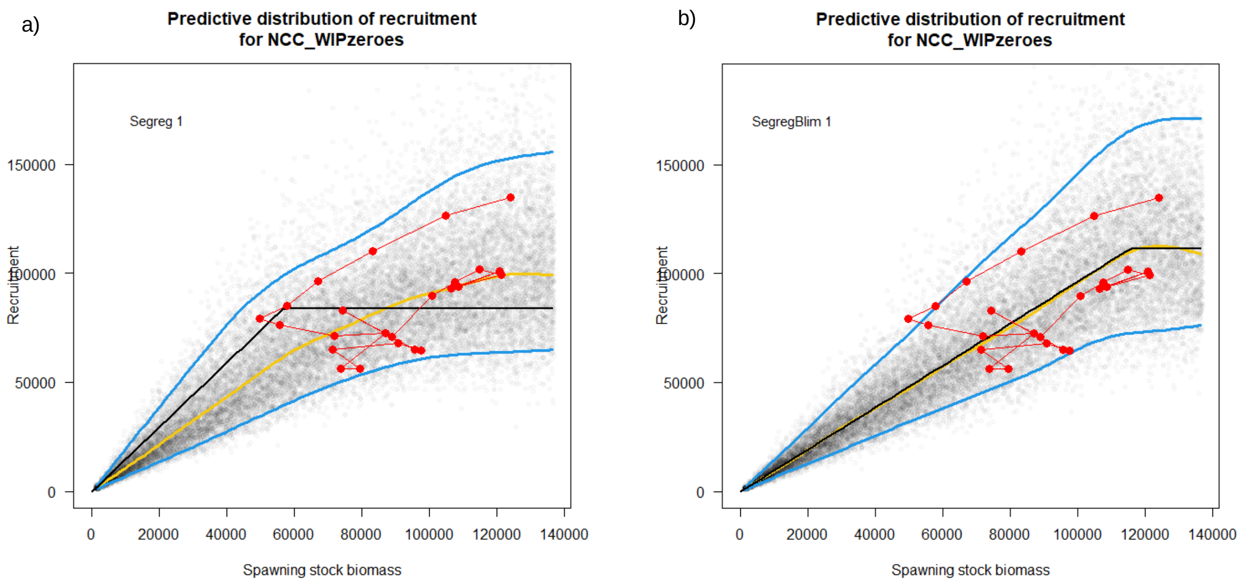


Figure 26: Simulations of the coastal cod stock-recruitment relationship from EQSIM. a) free segmented regression, b) constrained segmented regression, with manual specification of B_{lim} to the value approved by the benchmark. The yellow line corresponds to the median of the simulated points and the blue lines surround the 5-95 % quantiles.

An attempt was made to simulate F_{lim}, and MSY reference points from this B_{lim} using EQSIM. We stress that these reference points are highly uncertain. In the simulation, averages of the last 10 years were used for weight at age. For selectivity at age, averages of the last 5 years were used as there was a pronounced increase in selectivity of ages 7-9 in recent years (Fig. 27). This is likely related to changes in the cod fishery, targeting larger NEA cod individuals by using larger mesh sizes in nets as their proportion in the stock increased. This may have affected selectivity on the coastal cod stock in a similar way in areas where the two stocks overlap. The output from EQSIM and associated reference points are shown in figure 28. B_{lim} and F_{lim} are shown in relation to the SAM estimates of SSB and Fbar in figure 29.

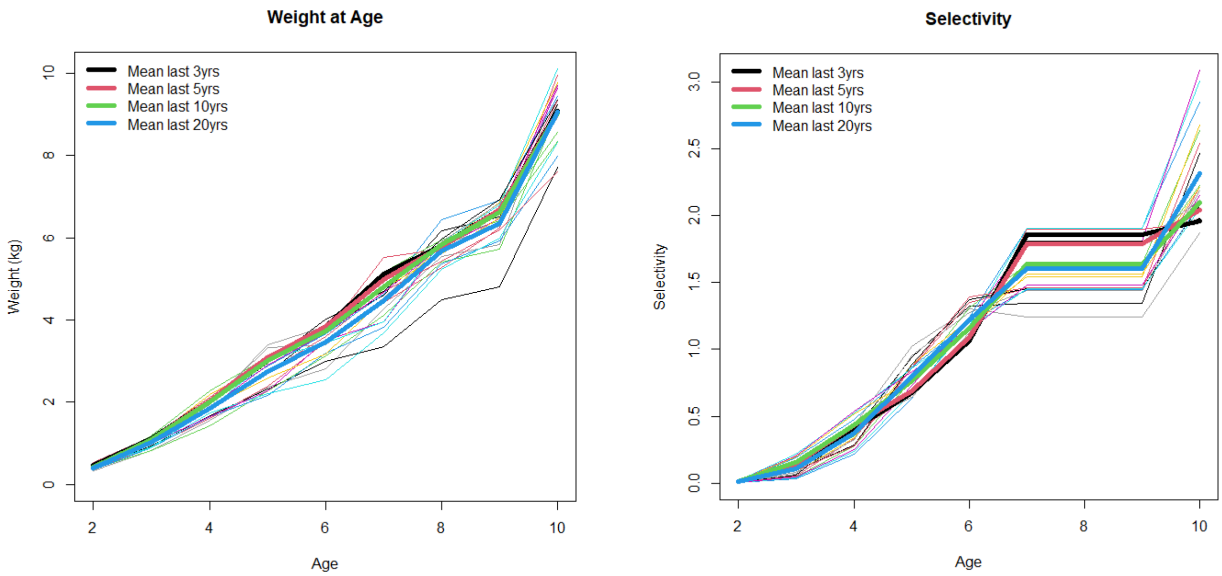
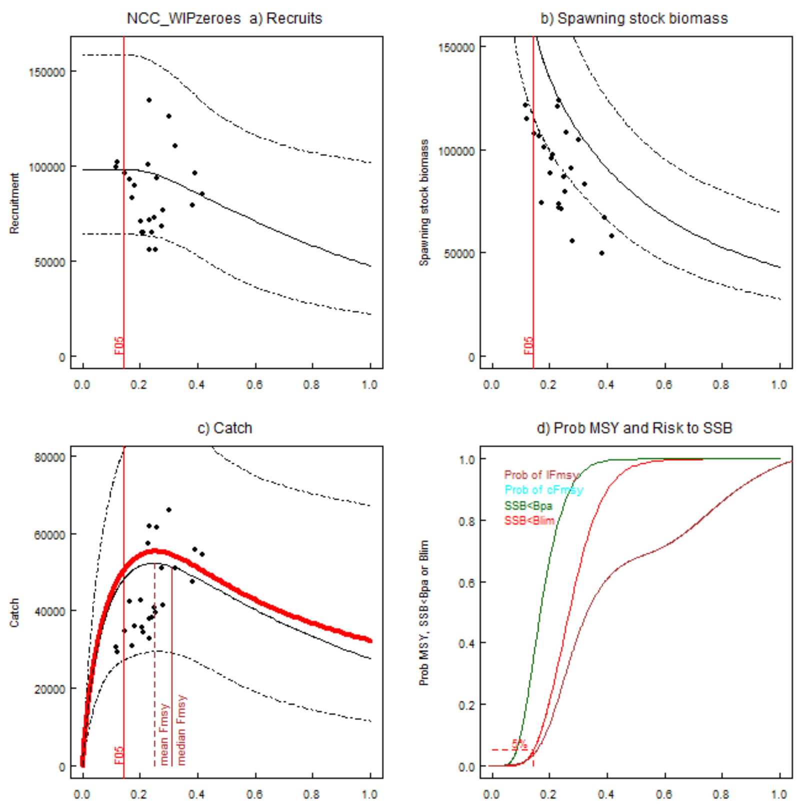


Figure 27: Mean weights at age (left) and selectivity (right) calculated for different number of years.



$MSY_{Btrigger}$	14783
5thPerc_SSBmsy	92443
B_{pa}	147843
B_{lim}	115782
F_{lim}	0.230
F_{p05}	0.144
$F_{msy\_unconstr}$	0.190
F_{msy}	0.144

Figure 28: Output from the EQSIM simulation. The estimated reference points are shown in the box to the right.

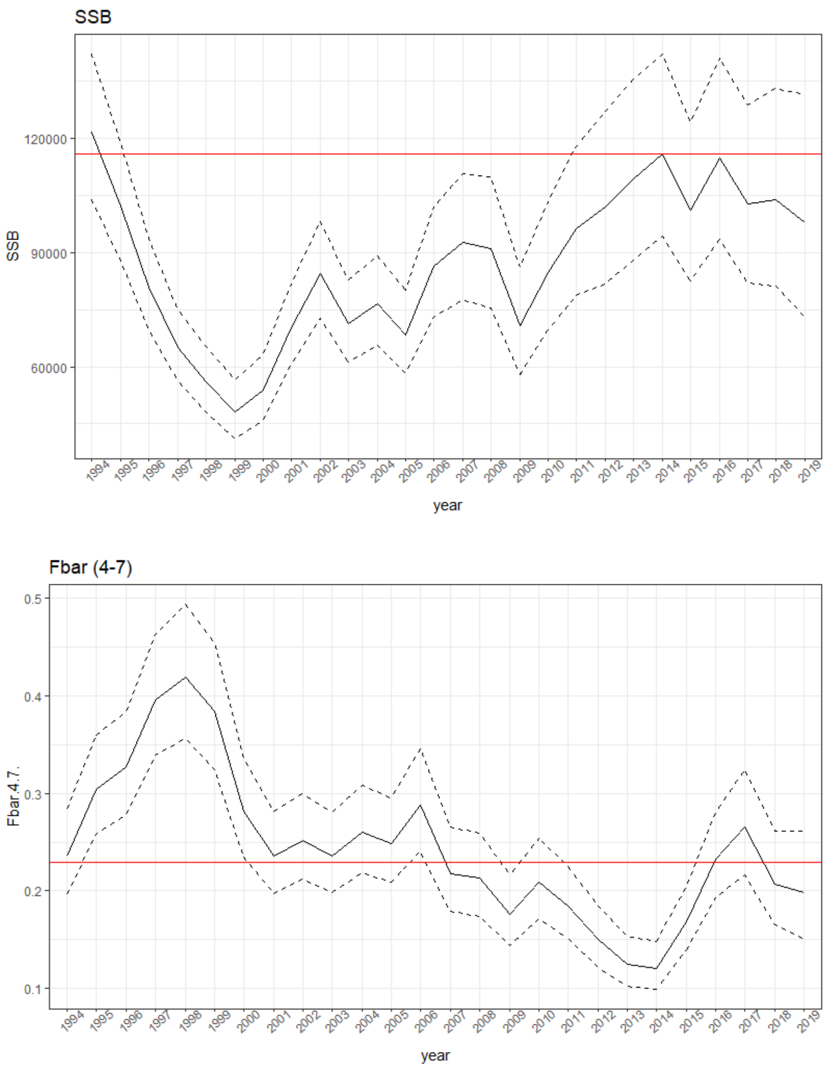


Figure 29: SAM estimates of SSB (top) and Fbar (bottom) in relation to the reference points B_{lim} and F_{lim} (red lines).

5. Conclusion and recommendations

The SAM presented here has been approved by the benchmark as a basis for category 1 assessment of Norwegian coastal cod north of 67°N.

The benchmark concluded that we have confidence in the assessment, but because of the range of observed SSBs and recruitments it is difficult to estimate reference points. The reported F target should not at this point be considered precautionary for advice. There is a need to develop a harvest control rule for this stock, and potentially a new rebuilding plan. All reference points should be subject to re-evaluation in connection with an MSE.

Several research recommendations were put forward during the benchmark:

- Investigate the age distribution in pelagic versus bottom trawl hauls in the coastal survey – does distribution in the water column vary by age and how does this affect survey indices?
- Continue to work on natural mortality; improving the size-based estimates, looking further into changes in M over time, and exploring other methods of estimation.
- Continue to investigate SAM configurations, particularly the correlation structures.
- Investigate ways of handling poor catch estimates in SAM – we may get better estimates of recreational catch for recent years once longer time series of this fishery has been obtained. Should the earlier, more uncertain recreational catches be downweighted?
- Investigate the use of longer periods for recruitment sampling in the short-term forecast.
- Do more work on reference points (via simulation, MSE, etc.).

6. References

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Working documents to WKBarFar 2021:

WD-7. Fotland and Nedreaas. Revised Norwegian catch-at-age data for cod 1992-2019 in Subarea 1 and 2.

WD-13. Nedreaas and Aglen. Data series on recreational and tourist fisheries for Norwegian Coastal Cod.

WD-14. Gjøsæter, Fall, Aglen. New abundance index series for Coastal Cod.

WD-18. Fall. Data and methods for calculation of Norwegian coastal cod natural mortality.

7. Appendix 1: Model estimates

Table A1: Estimated recruitment, spawning stock biomass (SSB), and average fishing mortality from the new SAM for Norwegian coastal cod north of 67°N.

Year	R(age 2)	Low	High	SSB	Low	High	Fbar(4-7)	Low	High	TSB	Low	High
1994	95641	69239	132111	121547	103855	142253	0.236	0.196	0.284	310802	274279	352187
1995	115128	87711	151117	102255	87981	118845	0.304	0.258	0.359	298811	267393	333922
1996	133394	100146	177680	80904	69811	93760	0.327	0.278	0.384	251055	224383	280899
1997	125083	95116	164493	64982	56336	74955	0.396	0.339	0.463	234383	207299	265005
1998	109286	84165	141906	56042	48065	65343	0.419	0.356	0.494	254621	223428	290168
1999	95348	73619	123489	48108	40953	56512	0.384	0.324	0.454	226086	198798	257120
2000	83896	64737	108723	53863	45885	63228	0.281	0.235	0.336	233386	205165	265489
2001	77747	59969	100795	70184	60293	81698	0.236	0.197	0.282	232537	204133	264893
2002	74963	58247	96477	84487	72817	98026	0.252	0.212	0.300	245807	216913	278549
2003	69867	55259	88335	71302	61337	82886	0.236	0.198	0.280	229585	202610	260152
2004	70820	56382	88954	76560	65700	89215	0.260	0.219	0.308	228544	200824	260091
2005	54433	41429	71519	68370	58368	80085	0.248	0.209	0.295	224263	196128	256435
2006	54521	41999	70778	86279	72971	102014	0.288	0.241	0.345	233932	204123	268094
2007	63057	49558	80233	92751	77729	110677	0.218	0.179	0.266	239191	206739	276736
2008	66381	52415	84067	91036	75448	109845	0.213	0.174	0.259	255014	219281	296570
2009	62873	48966	80729	70709	57999	86205	0.176	0.144	0.216	254075	218003	296114
2010	63324	49538	80947	84794	69617	103279	0.209	0.172	0.254	275798	236354	321825
2011	81264	64240	102800	96225	78658	117716	0.185	0.151	0.225	294994	251544	345949
2012	69324	54067	88886	101933	81818	126994	0.150	0.122	0.185	295748	250652	348958
2013	88175	69034	112622	109268	88135	135469	0.125	0.102	0.154	286539	242917	337993
2014	94112	73994	119701	115782	94312	142139	0.121	0.099	0.148	310808	265195	364267
2015	99790	77252	128903	101264	82542	124233	0.169	0.140	0.205	334968	286929	391050
2016	96940	74619	125937	114780	93475	140940	0.233	0.193	0.280	337869	288417	395799
2017	90956	68093	121495	102842	82150	128745	0.266	0.217	0.324	340304	284797	406629
2018	98256	71306	135393	103988	81237	133109	0.207	0.165	0.261	340685	275369	421494
2019	90967	63030	131289	97979	73058	131401	0.198	0.150	0.261	331379	257689	426141

Table A2: Estimated fishing mortality at age for Norwegian coastal cod north of 67°N.

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.000	0.005	0.040	0.153	0.313	0.435	0.435	0.435	0.744
1995	0.000	0.008	0.056	0.183	0.383	0.595	0.595	0.595	0.984
1996	0.001	0.016	0.087	0.225	0.412	0.583	0.583	0.583	1.036
1997	0.001	0.022	0.114	0.272	0.511	0.687	0.687	0.687	1.258
1998	0.002	0.035	0.191	0.401	0.561	0.525	0.525	0.525	0.980
1999	0.001	0.026	0.160	0.366	0.500	0.507	0.507	0.507	0.940
2000	0.001	0.018	0.123	0.289	0.365	0.346	0.346	0.346	0.656
2001	0.001	0.013	0.092	0.223	0.313	0.314	0.314	0.314	0.712
2002	0.001	0.012	0.084	0.216	0.343	0.367	0.367	0.367	0.778
2003	0.001	0.011	0.065	0.182	0.307	0.388	0.388	0.388	0.752
2004	0.001	0.009	0.056	0.162	0.320	0.502	0.502	0.502	0.880
2005	0.001	0.009	0.058	0.166	0.290	0.480	0.480	0.480	0.938
2006	0.001	0.012	0.070	0.207	0.344	0.531	0.531	0.531	1.261
2007	0.001	0.016	0.074	0.193	0.263	0.340	0.340	0.340	0.808
2008	0.001	0.017	0.070	0.204	0.270	0.308	0.308	0.308	0.577
2009	0.001	0.016	0.049	0.156	0.243	0.258	0.258	0.258	0.432
2010	0.001	0.020	0.057	0.181	0.293	0.306	0.306	0.306	0.533
2011	0.002	0.023	0.064	0.147	0.223	0.303	0.303	0.303	0.472
2012	0.002	0.029	0.071	0.130	0.181	0.218	0.218	0.218	0.361
2013	0.002	0.027	0.066	0.108	0.145	0.183	0.183	0.183	0.295
2014	0.002	0.025	0.066	0.101	0.138	0.180	0.180	0.180	0.301
2015	0.003	0.033	0.088	0.131	0.194	0.264	0.264	0.264	0.431
2016	0.003	0.032	0.099	0.148	0.262	0.421	0.421	0.421	0.564
2017	0.003	0.038	0.115	0.179	0.288	0.481	0.481	0.481	0.598
2018	0.002	0.024	0.079	0.138	0.218	0.395	0.395	0.395	0.459
2019	0.002	0.024	0.080	0.135	0.208	0.368	0.368	0.368	0.434

8. Appendix 2: SAM data input

Table A3: Coastal cod north of 67°N catch numbers at age (1000's) including recreational catches.

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	13	115	1148	5158	4414	3235	1313	356	793
1995	24	264	945	3183	5567	3672	2106	1094	711
1996	50	934	1720	2473	3805	3752	1471	659	709
1997	68	1326	2514	2334	2797	3248	2215	674	890
1998	523	1957	7718	5268	3341	1002	935	452	471
1999	97	1116	4152	6040	2492	957	644	482	520
2000	38	670	3201	4929	2812	1037	472	141	342
2001	13	442	2497	3006	2199	1288	409	140	661
2002	53	389	1959	3265	3019	1335	796	231	459
2003	156	454	1234	2408	2815	1562	754	399	326
2004	30	227	1352	1926	2774	1989	993	415	470
2005	17	307	1176	2525	2550	1862	911	324	440
2006	28	271	1556	2410	3193	2115	1240	490	482
2007	47	492	1567	2181	1737	1423	624	362	365
2008	81	498	1284	2458	1994	1294	741	358	369
2009	28	612	896	1582	1605	1091	563	579	284
2010	35	651	925	3474	2388	1295	647	347	1051
2011	83	597	1550	1690	1588	1386	728	440	747
2012	484	1317	1458	1447	1666	984	471	229	772
2013	179	689	1403	1421	1245	965	655	300	466
2014	119	680	1110	1695	1130	911	704	400	534
2015	407	1360	1734	1537	2089	1278	785	537	1072
2016	86	1086	2305	1835	1998	2458	1362	743	1244
2017	969	1806	2373	2661	2391	1707	1525	802	1035
2018	210	691	1800	2007	1873	1740	918	637	611
2019	13	115	1148	5158	4414	3235	1313	356	793

Table A4: Coastal cod north of 67°N catch weights at age (kg).

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.910	1.422	1.987	2.649	3.479	4.343	5.245	6.487	8.825
1995	0.784	1.272	1.708	2.236	3.073	4.203	5.228	6.121	9.469
1996	0.874	1.269	1.722	2.385	2.968	3.660	4.544	5.462	7.814
1997	1.115	1.490	1.902	2.497	3.219	3.930	4.738	5.616	7.768
1998	0.719	1.212	1.654	2.343	3.346	3.969	4.786	5.389	9.584
1999	0.989	1.512	1.975	2.501	3.331	4.032	4.923	5.415	8.339
2000	1.019	1.452	2.057	2.598	3.447	4.449	5.553	5.834	9.781
2001	1.014	1.448	1.905	2.593	3.266	3.756	4.498	4.794	7.711
2002	0.929	1.470	2.059	2.760	3.590	4.467	5.268	6.236	9.943
2003	1.082	1.687	2.180	2.944	3.754	4.672	5.417	5.713	9.070
2004	1.145	1.604	2.186	2.848	3.640	4.555	5.367	5.930	7.991
2005	1.112	1.622	2.249	3.017	3.539	4.371	5.233	5.981	8.320
2006	1.522	2.020	2.491	3.284	4.075	4.887	5.806	6.638	9.710
2007	1.072	1.546	2.168	2.968	3.987	4.925	5.781	6.871	9.771
2008	1.153	1.663	2.355	3.043	3.970	4.902	5.844	6.279	9.239
2009	1.331	1.761	2.502	3.328	4.196	5.218	6.178	6.516	9.248
2010	1.252	1.770	2.375	3.103	3.834	4.483	5.437	6.185	7.599
2011	1.080	1.689	2.310	3.031	3.906	4.681	5.941	6.422	8.346
2012	1.010	1.653	2.328	3.232	4.246	5.111	6.448	6.914	9.446
2013	1.107	1.674	2.295	3.122	3.997	4.873	5.892	6.800	10.104
2014	1.187	1.788	2.410	3.222	4.118	5.165	5.791	6.461	9.643
2015	1.055	1.545	2.192	3.030	3.745	4.724	5.601	6.482	9.044
2016	1.279	1.774	2.363	3.171	3.972	4.868	5.893	6.850	8.928
2017	1.316	1.785	2.468	3.225	4.077	5.014	5.977	6.933	9.356
2018	1.141	1.700	2.307	3.090	3.878	4.770	5.711	6.581	9.333
2019	1.431	1.904	2.615	3.254	4.116	4.868	5.748	6.562	8.561

Table A5: Coastal cod north of 67°N numbers at age (millions) from the acoustic tuning index part 1. The survey timing was set to 0.75-0.85.

Age/ Year	2	3	4	5	6	7	8	9	10+
1995	8.774	4.974	6.382	6.44	4.373	1.309	0.532	0.319	0.132
1996	9.025	8.592	4.576	5.306	2.723	1.022	0.213	0.032	0.024
1997	15.358	16.93	7.71	4.484	2.316	0.716	0.328	0.059	0.033
1998	6.757	8.524	8.261	3.717	1.53	0.7	0.102	0.122	0.045
1999	3.486	3.387	2.788	2.498	0.751	0.172	0.03	0.022	0.02
2000	7.439	5.831	3.939	3.853	2.825	0.622	0.258	0.071	0.032
2001	4.551	4.246	3.776	2.184	1.499	0.974	0.149	0.029	0.093
2002	2.071	2.532	2.926	2.075	0.97	0.596	0.293	0.106	0.124

Table A6: Coastal cod north of 67°N numbers at age (millions) from the acoustic tuning index part 2. The survey timing was set to 0.75-0.85.

Age/ Year	2	3	4	5	6	7	8	9	10+
2003	2.168	3.026	3.303	1.838	1.519	0.651	0.364	0.19	0.069
2004	2.657	2.795	2.553	1.68	1.097	0.37	0.21	0.118	0.072
2005	1.201	2.229	1.814	1.492	0.842	0.233	0.233	0.127	0.079
2006	1.822	2.618	2.23	1.374	1.603	1.037	0.13	0.089	0.027
2007	3.033	2.78	3.8	2.432	1.629	1.215	0.441	0.12	0.041
2008	1.739	1.684	1.511	0.985	0.761	0.399	0.225	0.097	0.074
2009	1.502	2.083	2.596	1.374	0.605	0.386	0.378	0.14	0.064
2010	2.502	2.852	2.244	1.68	0.582	0.309	0.432	0.229	0.195
2011	2.542	1.869	2.372	1.469	1.215	0.394	0.278	0.137	0.15
2012	2.163	3.47	1.829	1.157	0.768	0.492	0.254	0.109	0.221
2013	3.084	1.597	1.77	1.287	0.838	0.657	0.43	0.216	0.252
2014	3.969	2.889	2.005	2.721	1.542	1.103	0.426	0.443	0.322
2015	2.903	1.976	1.652	0.977	1.072	0.48	0.387	0.311	0.277
2016	2.572	2.433	1.883	1.976	0.726	0.536	0.393	0.142	0.256
2017	3.29	3.217	2.454	1.771	1.12	0.436	0.266	0.168	0.183
2018	2.615	2.008	2.321	1.375	1.002	0.427	0.366	0.167	0.187
2019	2.992	3.724	2.221	2.149	1.272	0.656	0.212	0.262	0.266

Table A7: Coastal cod north of 67°N numbers at age (millions) from the swept area index. The survey timing was set to 0.75-0.85.

Age/ Year	2	3	4	5	6	7	8	9	10+
2003	3.268	3.763	4.521	2.7	2.319	0.863	0.489	0.22	0.069
2004	2.201	2.396	2.602	1.463	0.722	0.359	0.181	0.046	0.063
2005	1.042	1.988	1.478	1.268	0.746	0.157	0.107	0.068	0.054
2006	2.156	2.623	2.946	1.554	1.026	0.941	0.171	0.107	0.023
2007	0.911	0.853	1.071	0.789	0.465	0.394	0.114	0.075	0.029
2008	1.822	2.795	1.883	1.419	1.145	0.58	0.348	0.161	0.094
2009	2.251	3.57	3.716	1.584	0.868	0.712	0.466	0.204	0.16
2010	2.353	3.268	3.385	2.397	0.784	0.383	0.733	0.317	0.328
2011	3.471	2.498	2.866	2.095	1.445	0.292	0.315	0.213	0.31
2012	3.218	4.485	2.784	1.537	1.042	0.93	0.411	0.2	0.346
2013	4.101	1.706	2.666	1.887	1.575	0.89	0.578	0.297	0.419
2014	5.448	4.026	3.034	3.521	2.016	1.388	0.465	0.364	0.337
2015	4.733	4.154	3.727	2.068	1.818	0.902	0.506	0.397	0.222
2016	4.433	4.522	2.61	1.995	0.746	0.735	0.413	0.203	0.21
2017	2.891	2.407	1.563	1.151	0.715	0.308	0.2	0.147	0.157
2018	3.197	1.916	1.879	1.049	0.748	0.323	0.183	0.128	0.168
2019	2.114	2.47	1.508	1.46	0.839	0.49	0.148	0.129	0.211

Table A8: Coastal cod north of 67°N stock weights at age (kg).

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.247	0.682	1.379	1.981	2.822	3.968	5.245	6.487	8.825
1995	0.282	0.719	1.395	2.091	2.767	4.693	5.228	6.121	9.469
1996	0.216	0.672	1.349	1.939	2.779	4.223	4.544	5.462	7.814
1997	0.244	0.655	1.393	1.914	2.921	2.988	4.738	5.616	7.768
1998	0.259	0.840	1.406	2.261	3.173	4.320	4.786	5.389	9.584
1999	0.272	0.793	1.508	1.964	2.759	4.257	4.923	5.415	8.339
2000	0.322	0.826	1.561	2.363	2.811	4.260	5.553	5.834	9.781
2001	0.377	0.933	1.660	2.320	2.998	3.338	4.498	4.794	7.711
2002	0.357	0.918	1.595	2.377	3.468	4.415	5.268	6.236	9.943
2003	0.361	0.820	1.427	2.269	3.127	4.114	5.417	5.713	9.070
2004	0.337	0.877	1.652	2.154	3.198	3.816	5.367	5.930	7.991
2005	0.436	0.878	1.725	2.205	2.545	3.674	5.233	5.981	8.320
2006	0.401	1.002	1.648	2.277	3.500	3.948	5.806	6.638	9.710
2007	0.485	1.065	1.864	2.581	3.170	4.520	5.781	6.871	9.771
2008	0.427	1.109	1.971	3.327	3.393	4.543	5.844	6.279	9.239
2009	0.357	1.032	1.877	2.694	3.804	4.600	6.178	6.516	9.248
2010	0.502	1.089	1.871	2.743	3.587	4.682	5.437	6.185	7.599
2011	0.401	1.165	2.279	3.109	3.702	5.163	5.941	6.422	8.346
2012	0.355	1.134	2.014	2.886	3.663	4.633	6.448	6.914	9.446
2013	0.384	0.918	1.817	3.041	3.438	3.963	5.892	6.800	10.104
2014	0.357	1.108	1.874	2.906	3.686	4.668	5.791	6.461	9.643
2015	0.369	1.083	2.181	2.969	3.842	4.763	5.601	6.482	9.044
2016	0.321	1.050	1.932	3.385	3.832	4.767	5.893	6.850	8.928
2017	0.507	1.063	1.959	2.944	4.023	4.695	5.977	6.933	9.356
2018	0.523	1.143	2.107	3.151	3.676	5.510	5.711	6.581	9.333
2019	0.372	1.131	1.984	2.983	3.815	5.141	5.748	6.562	8.561

Table A9: Coastal cod north of 67°N natural mortality at age.

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.687	0.504	0.407	0.364	0.327	0.295	0.271	0.254	0.231
1995	0.661	0.496	0.405	0.358	0.329	0.280	0.271	0.258	0.226
1996	0.716	0.507	0.410	0.367	0.329	0.289	0.283	0.267	0.240
1997	0.690	0.511	0.406	0.368	0.324	0.321	0.279	0.265	0.240
1998	0.677	0.473	0.404	0.350	0.316	0.287	0.278	0.268	0.225
1999	0.668	0.482	0.396	0.365	0.329	0.288	0.276	0.268	0.235
2000	0.634	0.476	0.392	0.345	0.327	0.288	0.266	0.262	0.224
2001	0.604	0.458	0.384	0.347	0.321	0.311	0.284	0.278	0.241
2002	0.615	0.461	0.389	0.345	0.307	0.285	0.270	0.257	0.223
2003	0.612	0.477	0.403	0.350	0.317	0.292	0.268	0.264	0.229
2004	0.625	0.467	0.385	0.355	0.315	0.298	0.269	0.261	0.238
2005	0.578	0.467	0.380	0.353	0.338	0.302	0.271	0.260	0.235
2006	0.593	0.449	0.385	0.349	0.306	0.295	0.262	0.252	0.224
2007	0.560	0.440	0.371	0.336	0.316	0.283	0.263	0.249	0.224
2008	0.582	0.435	0.365	0.311	0.309	0.283	0.262	0.256	0.228
2009	0.614	0.444	0.370	0.332	0.299	0.282	0.258	0.253	0.228
2010	0.554	0.437	0.371	0.330	0.304	0.280	0.268	0.257	0.242
2011	0.593	0.428	0.349	0.318	0.301	0.272	0.261	0.255	0.235
2012	0.616	0.432	0.362	0.325	0.302	0.281	0.254	0.249	0.226
2013	0.601	0.461	0.374	0.320	0.308	0.295	0.261	0.250	0.222
2014	0.614	0.435	0.371	0.324	0.301	0.281	0.263	0.254	0.225
2015	0.608	0.438	0.354	0.322	0.298	0.279	0.265	0.254	0.229
2016	0.635	0.442	0.367	0.309	0.298	0.279	0.261	0.250	0.230
2017	0.552	0.440	0.366	0.323	0.294	0.280	0.260	0.249	0.227
2018	0.547	0.431	0.358	0.316	0.302	0.267	0.264	0.253	0.227
2019	0.607	0.432	0.364	0.322	0.298	0.272	0.263	0.253	0.233

Table A10: Coastal cod north of 67°N maturity ogive.

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.028	0.174	0.417	0.657	0.852	0.899	0.952	1.000	1.000
1995	0.003	0.131	0.510	0.597	0.782	0.862	0.993	1.000	0.999
1996	0.021	0.142	0.384	0.736	0.842	0.916	1.000	1.000	1.000
1997	0.059	0.250	0.359	0.638	0.933	0.920	0.863	1.000	1.000
1998	0.032	0.128	0.236	0.556	0.698	0.976	0.932	0.877	1.000
1999	0.015	0.062	0.268	0.517	0.689	0.740	1.000	0.939	1.000
2000	0.002	0.056	0.196	0.508	0.683	0.797	0.923	1.000	1.000
2001	0.004	0.042	0.266	0.759	0.958	0.970	0.966	1.000	1.000
2002	0.010	0.112	0.297	0.783	0.887	0.978	0.937	1.000	1.000
2003	0.002	0.032	0.279	0.554	0.880	0.951	0.928	1.000	1.000
2004	0.009	0.104	0.299	0.782	0.918	0.938	1.000	1.000	1.000
2005	0.000	0.107	0.370	0.562	0.830	0.938	0.966	1.000	1.000
2006	0.010	0.193	0.526	0.717	0.926	0.901	0.962	1.000	1.000
2007	0.000	0.159	0.543	0.723	0.933	0.959	1.000	1.000	1.000
2008	0.017	0.101	0.298	0.734	0.879	0.971	1.000	1.000	1.000
2009	0.004	0.051	0.206	0.388	0.637	0.775	0.895	0.966	0.944
2010	0.000	0.029	0.269	0.565	0.780	0.924	0.987	0.979	0.967
2011	0.003	0.046	0.306	0.632	0.743	0.889	0.905	0.882	0.890
2012	0.006	0.045	0.276	0.554	0.855	0.881	1.000	0.958	1.000
2013	0.003	0.019	0.222	0.573	0.855	0.993	0.941	0.958	1.000
2014	0.002	0.027	0.157	0.551	0.781	0.907	0.988	1.000	1.000
2015	0.002	0.033	0.180	0.446	0.722	0.744	0.896	0.954	0.898
2016	0.001	0.046	0.272	0.596	0.875	0.923	0.982	1.000	0.976
2017	0.000	0.045	0.281	0.598	0.829	0.948	1.000	0.907	1.000
2018	0.002	0.082	0.229	0.604	0.784	0.929	1.000	1.000	1.000
2019	0.002	0.050	0.229	0.498	0.729	0.892	1.000	0.969	1.000

Table A11: Coastal cod north of 67°N proportion M before "spawning" (time of survey in late October).

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1995	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1996	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1997	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1998	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1999	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2000	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2001	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2002	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2003	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2004	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2005	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2006	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2007	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2008	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2009	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2010	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2011	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2012	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2013	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2014	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2015	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2016	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2017	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2018	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2019	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Table A12: Coastal cod north of 67°N proportion F before "spawning" (time of survey in late October).

Age/ Year	2	3	4	5	6	7	8	9	10+
1994	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1995	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1996	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1997	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1998	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1999	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2000	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2001	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2002	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2003	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2004	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2005	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2006	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2007	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2008	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2009	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2010	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2011	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2012	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2013	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2014	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2015	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2016	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2017	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2018	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2019	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

9. Appendix 3: SAM configuration

```
# Configuration saved: Wed Jan 27 12:03:27 2021
#
# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive
#
$minAge
# The minimium age class in the assessment
 2

$maxAge
# The maximum age class in the assessment
 10

$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
 1 1 1 1

$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
  0   1   2   3   4   5   5   5   6
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1

$corFlag
# Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, 2 AR(1), 3 separable
AR(1).
 2

$keyLogFpar
# Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by
fishing mortality).
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  0   1   2   3   3   4   5   6   7
  8   9   10  11  11  11  11  11  12
  13  14  15  16  16  16  16  16  17

$keyQpow
# Density dependent catchability power parameters (if any).
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1

$keyVarF
# Coupling of process variance parameters for log(F)-process (nomally only first row is used)
   0   0   0   0   0   0   0   0   0
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1

$keyVarLogN
# Coupling of process variance parameters for log(N)-process
 0 1 1 1 1 1 1 1 1
```

```
$keyVarObs
# Coupling of the variance parameters for the observations.
  0   1   1   1   1   1   1   1   1
  2   2   2   2   2   2   2   2   2
  3   3   3   3   3   3   3   3   3
  4   4   4   4   4   4   4   4   4

$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible
values are: "ID" "AR" "US"
 "ID" "ID" "AR" "AR"

$keyCorObs
# Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
#2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10
  NA  NA  NA  NA  NA  NA  NA  NA
  NA  NA  NA  NA  NA  NA  NA  NA
  0   1   2   3   3   4   4   5
  6   7   7   7   8   9   9   9

$stockRecruitmentModelCode
# Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and 3 piece-wise
constant).
 0

$noScaledYears
# Number of years where catch scaling is applied.
 0

$keyScaledYears
# A vector of the years where catch scaling is applied.


$keyParScaledYA
# A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange
# lowest and higest age included in Fbar
 4 7

$keyBiomassTreat
# To be defined only if a biomass survey is used (0 SSB index, 1 catch index, 2 FSB index, 3 total catch,
4 total landings and 5 TSB index).
 -1 -1 -1 -1

$obsLikelihoodFlag
# Option for observational likelihood | Possible values are: "LN" "ALN"
 "LN" "LN" "LN" "LN"

$fixVarToWeight
# If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1
fix variance to weight).
 0

$fracMixF
# The fraction of t(3) distribution used in logF increment distribution
 0
```

```
$fracMixN
# The fraction of t(3) distribution used in logN increment distribution
 0

$fracMixObs
# A vector with same length as number of fleets, where each element is the fraction of t(3) distribution
used in the distribution of that fleet
 0 0 0 0

$constRecBreaks
# Vector of break years between which recruitment is at constant level. The break year is included in the
left interval. (This option is only used in combination with stock-recruitment code 3)


$predVarObsLink
# Coupling of parameters used in a prediction-variance link for observations.
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1  -1
```