BENCHMARK WORKSHOP ON CAPELIN (WKCAPELIN)

VOLUME 5 | ISSUE 62

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
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ISSN number: 2618-1371

ICES Scientific Reports

Volume 5 | Issue 62

BENCHMARK WORKSHOP ON CAPELIN (WKCAPELIN)

Recommended format for purpose of citation:

ICES. 2023. Benchmark workshop on capelin (WKCAPELIN). ICES Scientific Reports. 5:62. 282 pp.
https://doi.org/ices.pub.23260388

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Contents

i Executive summary

The benchmark workshop on capelin (WKCAPELIN) was set up to develop benchmark assessments for the Barents Sea capelin and the Iceland-East Greenland-Jan Mayen capelin stocks. These stocks are distributed in ICES subareas 1, 2, 5, and 14.

For Barents Sea capelin, a modification of the existing model approach, which includes multi-species elements (predation by cod), was generally endorsed. Changes to the model approach that were endorsed in the meeting included using a type III rather than type II consumption model; a time averaged (most recent 5 years) CV at age for the autumn survey; 14 cm was to be used as the maturation length cut-off; M and F were now assumed to be constant from January to March; and the year used for the B_{lim} calculation was changed to avoid the early period of the time-series with a low herring stock. Despite these changes, the model results are relatively consistent with the previous assessment.

For Iceland-East Greenland-Jan Mayen (IGJM) capelin, a modified version of the existing model approach, which includes multispecies elements (predation by cod), was generally endorsed. The Autumn survey now has a maximum weight of 1/3rd in the final assessment. The revised model has lower biomass levels and B_{lim} than the previous assessment, but the relation between B_{lim} and average SSB is largely unchanged.

Both stocks are managed as escapement strategy fisheries, with $B_{escapement}$ based on B_{lim}. The only defined reference point is therefore B_{lim}, and there are no F reference points. B_{pa} is not needed for either stock, as the HCRs are explicitly based on having a 95% chance to avoid going below B_{lim}.

The workshop evaluated that the approach taken by Barents Sea and IGJM represents best available science following ICES procedures. The two existing HCRs are considered as precautionary as is typical for any ICES escapement strategy. Furthermore, the HCRs have functioned successfully for a number of years (since 1991 for Barents Sea, and since 2015 for IGJM). Provided no significant change is made to the HCR or to the performance of the underlying models, the rule should continue to be as precautionary as previously. It should be noted that the B_{lim} for the Barents Sea previously included a safety factor, raising $B_{escapement}$ to 200kt. Following current ICES procedures, the safety factor is no longer included in the B_{lim} value. However, the evaluation here that the existing HCR remain precautionary is based on a HCR in which $B_{escapement}$ retains the safety factor (i.e. remaining at 200kt). Any alternate HCR would require a separate evaluation.

ii Expert group information

Expert group name	Benchmark workshop on capelin (WKCAPELIN)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chairs	Daniel Howell, Norway (IMR)
	Hannah Murphy, Canada (DFO)
Meeting venues and dates	Benchmark workshop: 21–25 November 2022, Hafnarfjörður, Iceland (25 participants)
	L Data workshop: 30 November–2 December 2021, online meeting
	L Other meetings: 14 November 2022 and 3 March 2023, online meeting

1 Introduction

WKCAPELIN – Benchmark workshop on capelin

This WKCAPELIN benchmark report is split up into a section dedicated to Barents Sea capelin (cap.27.1-2; section 2) and one dedicated to IEGJM capelin (Iceland and Faroes grounds, East Greenland, Jan Mayen area; cap.27.2a514; section 3). Additionally, section 4 pertains to both capelin stocks and concerns a Harvest Control Rule (HCR) evaluation for the capelin escapement strategies.

2 Barents Sea capelin

cap.27.1-2 – *Mallotus villosus* in subareas 1 and 2 (Northeast Arctic), excluding Division 2.a west of 5°W

2.1 Introduction

The Barents Sea capelin assessment model works as follows (references to working documents given as appendices in brackets, overview of WDs given in Table 1):

The starting point is the autumn acoustic survey (BS0, BS3), which is assumed to be an absolute estimate of stock size. The stock is then divided into a maturing and an immature part assuming that the probability to mature and spawn depends on length only (BS9). The maturing stock is then predicted ahead from 1 October (end of survey) to 1 April (spawning time). In the period 1 October-1 January the natural mortality is assumed to be variable by year and is calculated based on survey data as described in BS6. In the period from 1 January to 1 April the natural mortality is assumed to be dependent on the abundance of the part of the immature cod stock which overlaps with mature capelin and is large enough to prey on maturing capelin (BS5, BS7). It is assumed that there is no growth in capelin length or weight during the period 1 October-1 April. The process is illustrated in Figure 1 and described in Gjøsæter *et al*. (2002).

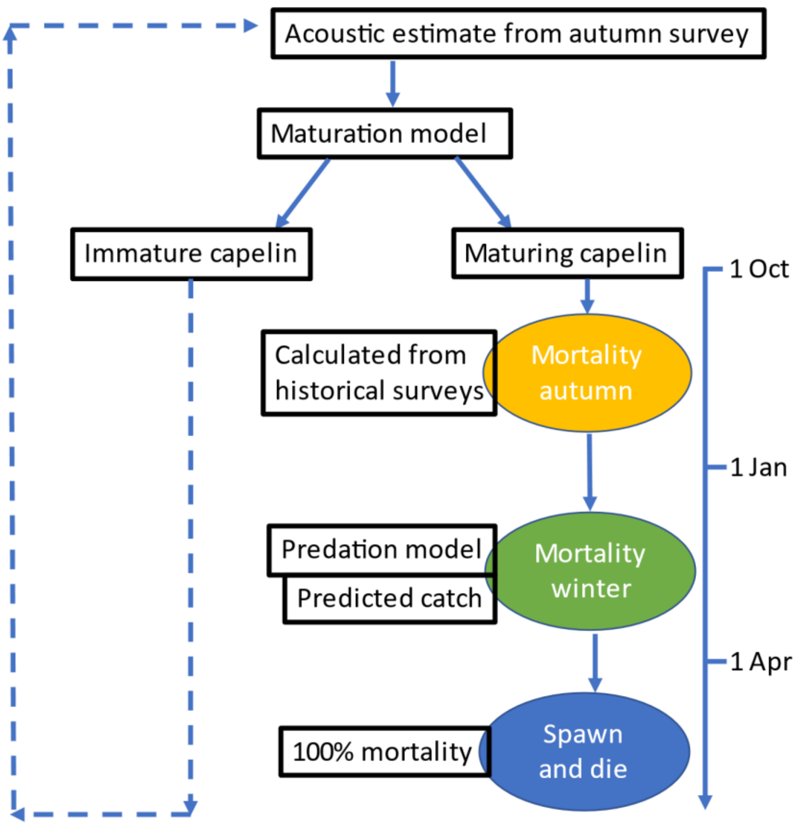


Figure 1. Schematic illustration of the capelin assessment model. The model runs from 1 October for a given year (end of acoustic survey) to 1 April the next year (assumed spawning time). The immature capelin are separated out by the maturation model and not included in the further modelling, but the immature survivors enter the survey the next year.

The current harvest control rule states that the TAC should not be set higher than that there is a 95% probability for the SSB to be above B_{lim} (currently 200 000 tonnes). To determine the catch advice, first a prediction is made with no catch. If that gives a probability higher than 95% for SSB to be above B_{lim}, a search is made to determine to the nearest 1000 tonnes the catch corresponding to 95% probability of SSB > B_{lim}. Approaches for revising B_{lim} are discussed in BS8.

Although the series of acoustic capelin estimates goes back to 1972 (Gjøsæter 1998), we have for several reasons mainly used data from around 1990 in the work presented here. This is related to the regime shift that occurred in the Barents Sea ecosystem after the 1983-year class of herring stayed in the Barents Sea from age 0 to 3 and had a strong negative effect on capelin recruitment, leading to a moratorium on the capelin fishery from 1987 to 1990 (Gjøsæter *et al*., 2009). The 1970s and early 1980s had been a period of high capelin abundance, relatively slow growth and fairly stable recruitment. The following capelin collapse had strong effects on the ecosystem. After 1990, the capelin stock has also fluctuated strongly due to variable recruitment, but with moderate ecosystem effects. This is a different regime to that of the 1970s and early 1980s. The management regime has also changed. Before 1986, there was a considerable fishery on a mix of immature and mature capelin in the autumn, and in general a heavy fishing pressure. The next fishing period, 1991–1993, can be considered a transition period, while the period from the reopening of the fishery in 1999 until present has had a management strategy with a much lower exploitation rate than previously and no autumn fishery. Another reason for excluding the early years in our work, is that cod stomach content data are only available back to 1984, which limits the predation calculations. However, the whole time-series was considered when evaluating data on maturation.

Due to the 2016 survey being an outlier compared to the 2015 and 2017 surveys, mentioned earlier in the report, data from this year are excluded in parameter estimation and when drawing survey-based mortalities randomly from historic time-series.

Table 1. List of working group documents related to BS capelin which are referred to in this report and which are attached at the end of the report. Yellow fill marks that the documents were updated during or after the benchmark meeting.

Number	Title	Authors
BS0	Description of capelin biomass estimation from BESS surveys	Georg Skaret *et al*.
BS1	Swept-area estimation from bottom trawl - method	Are Salthaug *et al*.
BS2	Swept-area estimation from bottom trawl - application	Harald Gjøsæter *et al*.
BS3	Abundance estimation from autumn survey - Selection of stations for allocation and survey CV	Georg Skaret
BS4	Spawning survey – summary of results and suggestion for application	Georg Skaret *et al*.
BS5	Cod consumption – description of assumptions and data	Bjarte Bogstad
BS6	Basis for the estimation of autumn mortality	Georg Skaret *et al*.
BS7	Predation model – description of model and simulation runs	Magne Aldrin *et al*.
BS8	Basis for deciding on reference point (B_{lim})	Georg Skaret *et al*.
BS9	Maturation model	Bjarte Bogstad *et al*.
BS10	Estimation of maturity parameters based on catch data	Sondre Hølleland

2.1.1 Swept-area estimation of capelin based on demersal trawls (BS1 and BS2)

Since 2004, demersal trawl hauls on a fixed grid have been carried out as part of the standard sampling during the Barents Sea Ecosystem Survey (BESS). Most of these hauls which are taken within the distribution area of capelin, catch capelin (BS1 and BS2). The catch sizes range from a few individuals to several tonnes. In most cases, the capelin caught are not visible on the echogram likely since they are present within the acoustic dead zone. Capelin from the demersal hauls are typically bigger than the capelin caught in the pelagic hauls, and are believed to be a component separate from the pelagic capelin.

At present, the bottom capelin are not included in the abundance estimate. BS1 describes a method for providing swept-area estimates from these hauls while handling hauls with very big catches which may strongly bias estimates. An outlier index was calculated based on the density of fish >7.5 cm estimated from the demersal hauls. For each trawl haul with density larger than zero density in the trawl haul was divided by the median density of nonzero densities in the same year/survey. For example: if the density in a trawl haul is two times greater than the median, then the outlier index is 2. The outlier index is estimated by year, but the index values can be combined to remove outliers over the entire time-series.

In a second step the effect of different outlier index cut-off points for excluding demersal hauls from the estimate is evaluated. In addition, it is evaluated whether a combination of acoustic estimates and swept-area estimates provide a more accurate estimate than acoustic estimates alone. For the evaluation, internal consistency in numbers-at-age between surveys in consecutive years (comparing age groups 1–2, 2–3 and 3–4) is used. The internal consistency is measured as the correlation of N at age *a* in year *y* versus N at age *a+1* in year *y+1*. The results show that the combined estimates provide better consistency than acoustic estimates alone, and that consistency is improved until an optimum point is reached after which it decreases. The optimum point varies between the age groups that are compared and is not very well defined.

In BS2 the method and estimated cut-off point from BS1 is used to estimate abundance and biomass of capelin for the time-series 2004–2021. The 10 highest outliers were removed, and the result shows that a typical biomass estimate from the demersal hauls is in the range of 50 000–150 000 tonnes. In high capelin years the relative contribution to the total biomass is very low, but in low capelin years the relative contribution is significant. However, the estimate is very sensitive to where the cut-off point is. A slight change in cut-off increased biomass for some years with several hundred thousand tonnes. A sensitivity test was run during the meeting, increasing the cut-off point from removing 10 to removing 20 outliers. Biomass still decreased significantly for some years with this change supporting that the estimate is sensitive to the cut-off limit.

If the current cut-off limit of 10 outliers (or a higher cut-off limit) was accepted, the swept-area estimate would not affect the catch advice much since the relative impact of the swept-area estimate is small when biomass of maturing capelin is high. However, it would affect the estimation of the reference point (B_{lim}), since this is based on years with low estimated spawning biomass. In case it is decided to use the swept-area estimates, it must be decided how to deal with them back in time. In particular, it is important for the year(s) which are used to set the B_{lim}. Currently, the year 1990 is used, so bottom trawl estimates from the autumn of 1989 should be used if possible. For several of the years prior to 2004, there is varying degrees of spatial coverage of bottom trawl stations which may contribute to extend the time-series.

During the meeting it was discussed whether the outliers represent a different component of the capelin stock (pelagic component) and should be excluded for that reason and not only because they are numerical outliers. This must be looked further into by consulting acoustic data. It was found that the mean size at age 2 is higher in swept-area estimates than in the acoustic estimates while there was no clear difference for older age groups.

There is also a need to find a way to combine the uncertainty from the acoustic and swept-area data if the estimate is going to be used for assessment.

The recommendation from the benchmark group was that bottom capelin should not be included in the estimate at this stage due to the sensitivity and uncertainty related to the removal of outliers. But the group strongly recommended that work should be done to include them, possibly through a specific mini review ('interbenchmark'). In principle the demersal capelin should be included since they make up a capelin component which is currently not included in the estimate. However, more work needs to be done to deal with the outliers, to estimate uncertainty in the combined biomass, and to validate estimates projected back in time where possible.

2.1.2 Abundance estimation from the autumn survey – selection of stations for allocation and survey CV (BS3)

The BS capelin abundance estimate from the acoustic trawl survey in the autumn is a key input to the assessment. For the meeting two topics related to the survey were presented and discussed (BS3). The first was how to allocate capelin length distributions from trawl hauls in the conversion from acoustic backscatter to capelin abundance and biomass. The second was the implementation of uncertainty estimates associated with the survey abundance estimates.

In the capelin abundance estimation process, capelin length distributions from trawl hauls are allocated to the acoustic data to convert acoustic backscatter to abundance and biomass. In the Barents Sea ecosystem survey, there are three types of trawl hauls which all catch capelin: 1) Pelagic hauls for 0-group fish at fixed positions fishing in the three depth steps 0, 20 and 40m, 2) Demersal hauls for bottom fish at fixed positions and 3) Target hauls for aggregations of capelin. The length distributions from these hauls are very different, and the allocation and weighting of the hauls therefore matter for the estimate.

In the current assessment, the length distributions from the hauls are weighted according to the acoustic backscatter (in units of Nautical Area Scattering Coefficient; NASC; m^2/nmi^2) within a 10 nautical mile radius. All the pelagic 0-group hauls and all the target hauls are allocated, while it varies from year-to-year which demersal hauls are included. A fixed procedure for allocation would be desirable.

In the sensitivity test presented in BS3, a scenario with all hauls selected and only target hauls selected were compared to the original selection of trawl hauls. The scenario with all hauls selected provided systematically higher abundance of age 3 capelin than the original allocation, and lesser abundance of age 1 capelin. It also produced systematically higher biomass of maturing capelin. The scenario with only target hauls selected provided systematically higher abundance-at-age 2 than the original allocation, but lesser abundance-at-age 3. When selecting only target hauls, there was no systematic deviance in the biomass estimate compared with the original selection, but in some years the maturing biomass was estimated considerably lower than with the original selection.

In order to evaluate the quality of the estimates based on the different selection of stations, the consistency in numbers-at-age from one year to the next was investigated. This is measured as the correlation of N at age a in year y versus N at age $a+1$ in year $y+1$. Age groups 1–2, 2–3 and 3–4 were compared. There was low internal consistency when all stations were selected. This supports the notion that length distribution from demersal hauls that often target capelin in the acoustic dead zone (BS1 and BS2) are not representative of what is recorded acoustically. The internal consistency was similar when comparing estimates based on target haul selection with estimates based on original selection.

The benchmark meeting noted that the scenario with removing all demersal hauls (while keeping only 0-group hauls and pelagic target hauls) had not been tested as part of the evaluation. The meeting therefore recommended to evaluate the removal of all demersal hauls further and forward it as part of the planned mini review where also the possible inclusion of swept-area estimates from bottom trawl (BS1 and BS2) will be evaluated.

The survey uncertainty which is currently used in the capelin forecast is a fixed CV of 0.2 per age group. This is based on Tjelmeland (2002). Previously, there were practical difficulties in estimating CV from a survey in the short time interval between the end of the survey and the start of the assessment meeting. This is no longer an issue, and survey CV has been estimated in Stox after each survey since 2017. CV has been calculated back to 2004 and the proposal in BS3 was to use the empirical CV in the forecast instead of a fixed value of 0.2.

To evaluate the effect of a change in capelin CV on the advice, the existing (later denoted also as 'old') forecast model was run for most of the years in the series 2004–2021 with annual CV estimated from the survey, and with the mean of the annual empirical CVs added to the input data. Overall, changes of CV in the range that was tested, had relatively little impact on the results of the forecast. However, in years with unusually high CV, the catch advice was reduced (for the year with highest CV, 2009, it was reduced from 240 000 tonnes to 77 000 tonnes). Conversely, in years with low CV, catch advice would have been higher.

Two concerns were raised during the meeting against the use of an annual CV estimate in the assessment. The first regards whether the CV is a good estimate of survey uncertainty (that is, sampling uncertainty), or whether it mostly tracks noise. For the time-series back to 2004, there is a slight negative trend in CV over time which coincides with an increased survey effort. There are also indications of lower CV with higher abundance-at-age which one would expect if distribution area increased with increasing abundance and distribution patchiness decreases.

The second concern was related to some years of very low CV (around 0.1). The question is whether the CV in such cases is still is a major component of the total uncertainty, or whether other sources of uncertainties in these cases contribute more to the total uncertainty than the sampling variance. The group did not have an answer to where the lower bound of a CV realistically reflecting survey uncertainty would be, but the opinion of the group was that a CV of 0.1 was very low and might be an underestimate of total uncertainty.

The recommendation from the benchmark meeting was to use a five-year average CV at age for the autumn survey. This allows for the impact of recent survey quality without being too vulnerable to occasional year with extremely low estimated CV. If there is an expert judgement that the autumn survey is of unusually poor quality in a given year, then the annual CV estimates for that year should be considered. Strong effort should be placed on finding a precautionary method to use the annual CVs, as these account for poor survey years and would correctly allow for improvements in survey quality to be associated with increased catches.

The group also questioned the number of replicates used in the estimation of uncertainty. Currently, 1000 replicas are used and 10000 were tested to evaluate the impact of increased number of bootstrap replicas on the estimated CV. The impact was low for age groups 1–3 (change of 0.01–0.02 in estimated CV), but high for age group 4 with very few individuals present. It was recommended that 10000 replicas are used in future assessments, since the cost of running this is low.

2.1.3 Spawning survey (BS4)

A capelin spawning survey has been run annually along the coast of north Norway during the first two weeks of March from 2019–2022 as described in BS4. The timing of the survey is picked so that it would not be too early for the capelin to be in the area, and not too late to be able to give useful advice. A similar survey was tried during 2007–2009, but both design and results were then inconsistent. In the four surveys conducted during 2019–2022 the design, coverage and timing have been fairly consistent. The survey is conducted with two rapid repeated coverages over 6 strata using zig-zag transects.

The biomass estimates from the survey typically show high sampling variance likely reflecting high degree of patchiness in the distribution (e.g. CV of 0.42 in 2022 where there was fairly high abundance). There is also typically more capelin in the second coverage than the first reflecting rapid changes in distribution. A methodological challenge in the survey is the variable acoustic response observed, likely due to capelin emptying the swimbladder. The assumed relationship between target strength and length assumed currently in the assessment is only valid for capelin with filled swimbladder.

Still, the estimates are within the uncertainty range of the prediction from the autumn survey in all years, but always on the low side of the prediction. Estimates on the low side are expected, since there is no coverage in Russian waters.

The benchmark group acknowledged that the results from the spawning survey had been very useful in validating the assessment model. The results from the survey had also provided valuable validation of the autumn survey results. The benchmark group did not recommend using the spawning survey to revise the quotas in the harvest control rule. However, the benchmark group does recommend that the spawning survey be used as a potential fall-back basis for quota setting in the event of a failure in the autumn survey. Such failures occurred in the 2014 survey due to ice cover and in 2022 due to lack of coverage in Russian EEZ, in both those years the capelin abundance in the uncovered area was extrapolated when giving advice. The group noted that given that it is unlikely to obtain 100% survey coverage, it should provide a precautionary estimate of biomass. The group suggested that a future use of the survey results to update the quota advice could be to alter the original catch advice upwards if the results indicate that, or else keep the original advice from the autumn.

2.1.4 Capelin maturation model (BS9+BS10)

The assumption in the BS capelin assessment, is that only capelin that are maturing will migrate to the coast to spawn and make up the component of potentially harvestable biomass. For BS capelin, an estimate from the autumn when maturing and immature capelin are mixed is used as input for the assessment. It is therefore very important for the assessment that the component of maturing capelin is separated from the immatures in a reliable manner. In the assessment, this separation is done according to their length. Data show that there is a slight difference in proportion maturing at length between females and males, but the difference is not accounted for in the assessment.

The proportion maturing as a function of length is described by a curve with a 'steepness of slope' parameter, P1, and a length at 50% proportion mature (L50) parameter, P2. In the current assessment, the P1 is fixed at 3.5, which is close to a cut off and P2 is 13.89 ± SD 0.075 cm. In practice, since the capelin is measured in 0.5 cm bins, this is close to a cut-off at 14 cm. These values of P1 and P2 are estimated using data from the early years in the BS capelin time-series (1972–1980) when survey mortality was quite stable. The estimation is based on a comparison of number of immatures at age 2 in year Y against total number-at-age 3 in year Y+1, as well as immatures at age 3 in year Y against total number-at-age 4 in year Y+1.

The observed length distributions in the catches and spawning survey data show that a very small proportion of the fish is under 14 cm, which supports that the cut-off limit is not set too low. But they do not tell if the present cut-off overestimates the proportion maturing over 14 cm (i.e. are there fish bigger than 14 cm that did not mature?). The sensitivity of the estimate to change in P1 and P2 was investigated during the meeting. A change in the cut-off length from 14 to 13.5 cm resulted in about 10% change in biomass on average, and 20% change with a reduction to 13 cm. A comparison made using P1 at 0.6 (shallower slope) but same P2 had little impact on the proportion maturing over the time-series. A shallower slope makes more sense from a biological perspective than a cut-off.

Prior to the meeting, we re-estimated the maturation parameters. We then re-estimated both P1 and P2 comparing abundance of immature capelin at age 2 in survey year y with abundance of capelin at age 3 survey year y+1. When assuming P1 and P2 constant over time, annual mortalities can be estimated, and the values of P1 and P2 that minimize an objective function (formula in BS10) comparing number of immatures at age 2 in year y with number of age 3 capelin in year y+1 can be found. The results were dependent upon the initial value of P2 used in the estimation, suggesting that the optimization was not correctly set up.

During the meeting, we re-estimated P1 and P2 comparing against numbers at length in the catches. The estimation is described in BS10 and used the R-package bifrost[1] IMRpelagic/bifrost: Capelin assessment version 0.0.0.9000 from GitHub (rdrr.io). In a first run, we estimated both P2 and P1. In a second run we estimated P2 with P1 kept fixed at 3.5. When keeping both P1 and P2 free, the estimated values were 0.343 (quite shallow slope) and 15.03 cm respectively. When estimating only P2, the estimate was 13.79 cm which is close to the old P2 of 13.89 cm. The comparison against catches assumes no growth between autumn and spring which might not be true. It also assumes no size selectivity in the catches, which might also not be true since the fishery in recent years happens in February/March targeting the migrating fish prior to peak spawning, while smaller fish tend to spawn later in the season.

The recommendation from the benchmark group was to keep parameters used currently since the re-estimation of P2 keeping P1 fixed gave similar result as the value of P2 currently in use. There are, however, indications that a higher cut-off and a shallower slope would have been more appropriate, and there is a strong recommendation from the group that this should be looked further into using both survey data and catch data.

Since the difference between the maturation model with P1 and P2 and a 14 cm cut-off in practice is small, and a 14 cm cut-off was used in the modelling work, the final recommendation was to use a 14 cm cut-off for all data and model.

2.1.5 Revision of basis for the mortality used in the autumn stock forecast (BS6)

In the assessment of the BS capelin, there is an autumn forecast of the maturing part of the stock – in the present implementation going from 1 October to 1 January. Survey mortality is used to estimate natural mortality in the autumn. In the current assessment the mortality is estimated year by year. Replicates (N=1000) from the estimation are used in the practical assessment for the annual autumn forecast. Mortality estimates from the years 1980–1985, 1990–1993 and 1997–2002 have been selected and used. In each simulation run, a value from one of these years is randomly

[1] https://rdrr.io/github/IMRpelagic/bifrost/

picked. The autumn mortality estimates are also used when estimating C_{max} and $C_{1/2}$ in the cod-capelin consumption model (See BS5 and BS7).

There were some suggestions in BS6 on how to update the existing estimates. It was agreed that survey mortality from age 2–3 likely reflects the mortality of maturing capelin better than survey mortality from age 1–2. It was further agreed that the survey years prior to 1987 (i.e. 3-year olds measured in 1988 compared to 2-year-olds measured in 1987 is the first pair included) should be removed from the estimation since they represent a period when the ecosystem was in a very different state than in more recent years (Table 2). It was further agreed that estimates associated with the problematic survey year 2016 should be removed. The resulting estimates to be included in the assessment and cod-capelin consumption estimation are shown in table 2. Note that negative values are retained when using this alternative. They reflect that the survey may underestimate maturing biomass in some years, and maturing biomass is therefore allowed to increase from 1 October to 1 January in these cases.

The benchmark group recommended that the survey M used for the forecast in the annual assessment should be picked randomly from this list for each simulation run, and the list should be updated annually unless there are issues with the survey.

Table 2. Estimates of annual and monthly Z based on survey mortality from age 2 (immatures) in year Y to age 3 in year Y+1 assuming a length cut-off at 14 cm for separating immatures from matures. The survey year in the table refers to year Y.

Survey year	Annual Z	Monthly Z
1987	0.89	0.07
1988	1.89	0.16
1989	-0.52	-0.04
1990	0.65	0.05
1991	1.32	0.11
1992	2.30	0.19
1993	2.41	0.20
1994	0.23	0.02
1995	0.49	0.04
1996	0.10	0.01
1997	0.85	0.07
1998	0.30	0.02
1999	0.32	0.03
2000	0.48	0.04
2001	1.10	0.09
2002	1.90	0.16
2003	0.37	0.03

Survey year	Annual Z	Monthly Z
2004	0.97	0.08
2005	0.16	0.01
2006	-0.14	-0.01
2007	-0.33	-0.03
2008	0.67	0.06
2009	0.48	0.04
2010	0.46	0.04
2011	0.34	0.03
2012	0.43	0.04
2013	1.52	0.13
2014	1.66	0.14
2017	0.87	0.07
2018	1.31	0.11
2019	-0.20	-0.02
2020	0.38	0.03
Average	0.74	0.06

2.1.6 Cod-capelin consumption model (BS5 and BS7)

Prior to and during the benchmark meeting the cod-capelin consumption model was evaluated. Several of the model assumptions were evaluated, parameters were re-estimated and input data updated.

2.1.6.1 Data

The input data used in the estimation were made using data from the period 1990–2020 (survey year):

- Autumn estimates of capelin abundance
- Capelin mortalities in October-December based on annual survey mortalities
- Monthly catches of maturing capelin in tonnes from October-March
- Annual estimates of cod abundance, weight at age and maturity-at-age
- Annual proportion by age group of immature cod which overlaps with mature capelin
- Empirical estimates of maturing capelin eaten by cod in the period January-March

Although the maturation length is estimated to be slightly below 14.0 cm as described above, a cut-off at 14.0 cm is used to distinguish between immature and maturing capelin both for the autumn acoustic estimates, in the catch data and data on consumption by cod. The historic catch data were assumed to be correct and were not scrutinized further.

2.1.6.2 Model

The consumption rate K_t (biomass consumed per month) is based on a Holling's type III response function with exponent 2 and is the instantaneous intake rate of maturing capelin by non-mature cod. It is given by

$$K_t = [(C_{max}B_t^2)/(C_{1/2} + B_t^2)]P_m,$$

where B_t is the capelin biomass at t in a month m, P_m is the predation ability for cod (assumed to be constant within a month) and C_{max} and $C_{1/2}$ are parameters to be estimated. The predation ability is calculated from the abundance of immature cod which overlaps with maturing capelin in the period January-March. A type II function (i. e. replacing the exponent 2 in the equation above by 1) was also investigated, but a type III function was found to be the most appropriate (See BS7). Exponents other than 1 and 2 were not investigated.

It was further assumed that the estimate K^{tot} for the total consumption in sum over the three months in the consumption year is normally distributed with expectation equal to the true consumption and with variance σ^2. The variance is currently constant, but this may be changed. No uncertainty on acoustic estimates or other data and parameters was accounted for. The parameters C_{max} and $C_{1/2}$ are estimated by maximum likelihood by fitting the model to the corresponding empirical consumption estimates K.

Data for 2016 is not used for estimation, because the survey biomass in this year is unreliable. The results are shown in BS7. 1000 replicates of the predation parameters were calculated. Runs using those replicates were made after the meeting and are discussed in the next section.

Some points to note

The effect on parameter estimates of the constraint of SSB at 1 April not becoming negative, should be investigated.

The maximum capelin consumption of a 1 kg cod (typical size of age 5 cod) in the model is about 0.15 kg per month, corresponding to about 1.8 kg per year. This is on the low side compared to other estimates of annual food consumption by cod. Bogstad and Mehl (1997) reported a mean value of 0.66 % of body weight per day for age 5 cod, i.e. 2.4 kg/year. Here one should consider that January-March is a period with higher feeding rate than the rest of the year, although one should also note that cod consumes other food objects than maturing capelin. The consumption function levels out at around 500 000 tonnes of capelin biomass, which seems like a plausible value.

The predation model used in the previous model was a type II model. However, the parameter replicates from that model had a very wide range of numerical values, meaning that the biomass of capelin in that model (Bt in the equation above) in most cases was negligible in the predation equation, thus the model as implemented was essentially a type I model with consumption proportional to available food.

Adding bottom trawl estimates to acoustic estimates will make the issue of avoiding negative SSB less of a problem.

2.1.7 Model runs and comparisons done after the meeting

To explore the differences between the new model and the one previously used, we ran half-year predictions with the new data and parameters, as described above, and calculated the SSB on 1 April for the survey years 1987–2021. The medians correspond closely to those estimated and shown in BS7. The years 1987–1989 and 2021 were not included in BS7 and thus no comparison can be made for those years.

The SSB resulting from the new model is shown in Figure 2. The shaded area indicates the 5–95% range of SSB. In Figures 3 and 4, we show a comparison between the output from the old and new model, comparing both autumn mortality estimated from the mortality observed in the surveys, and winter mortality imposed by the modelled consumption from cod. This comparison was run only for the years 2004–2021 to illustrate the difference, as data before 2004 with the old model configuration were not easily available. Note the generally higher values and wider uncertainty range for cod consumption in the old model in Figure 3 (upper panel). It seems like the higher values in the old model is due to the old implementation being in practice a Type I model (see section above) with consumption proportional to available food and no saturation within the observed range of food available. With a type III model in the new implementation, saturation is reached and the function levels out at a capelin biomass of ca. 500 000 tonnes (BS7). The wider uncertainty range in the results from the old model is likely due to an implementation using consumption calculations based on individual stomach data and thus taking more variability into account compared to the average values of stomach content used in the consumption calculations for the new model. We also checked that these results are consistent with those presented in BS7.

In Figure 4 we compare the biomass removed through M in October-December and in January-March with the old and new models, and the annual M values used in the new model for the period October-December are also shown. The biomass removed by predation is higher than that removed by M in autumn for all years (except 2013 with the new model) with both models, which is expected from what we know about the seasonal variability of cod feeding on capelin (Holt *et al.*, 2019).

Figure 5 shows the SSB time-series based on the old and new model. We see that for most years with high stock size, the time-series based on the old model gives a considerably lower SSB than the series based on the new model. The differences are both due to differences in autumn M value and to the change in the consumption model.

In the new model runs the median SSB in 2015 is calculated to be slightly below 0. This is surprising given that a fishery was advised (and carried out) in 2015 and thus the SSB must have been predicted to be relatively large. In the old model 95% probability of SSB > 200 000 tonnes correspond to a median of 400 000–500 000 tonnes. However, the circumstances for the survey in 2014 and the assessment process were unusual. The area coverage was incomplete as part of the usual capelin distribution area was covered with ice. Thus, a compensation for the lack of coverage was added to the survey estimates based on historical distribution. However, results from the 2015 survey called into question the validity of the compensations made (ICES 2016, section 9.5.3), and the 2014 survey estimate has later been included in the time-series without any compensation. This difference likely contributes the most to explaining the negative median SSB in 2015, although it should also be noted that the autumn M derived from survey mortality is higher in the new than in the old model. It could be useful to investigate the effect of excluding this year from the parameter estimations.

Further, we re-ran the prediction used for quota advice for 2022 (based on the 2021 survey) with new data and model, which gave a quota advice of 160 kt compared to the original advice of 70 kt. The effect of updating the cod abundance with data from the 2022 assessment had a very small effect (not updating would have given 157 kt instead). Due to the issues with extrapolation of a large uncovered area (Russian EEZ) in the quota advice for 2023 we decided to not re-run the predictions which this advice was based on.

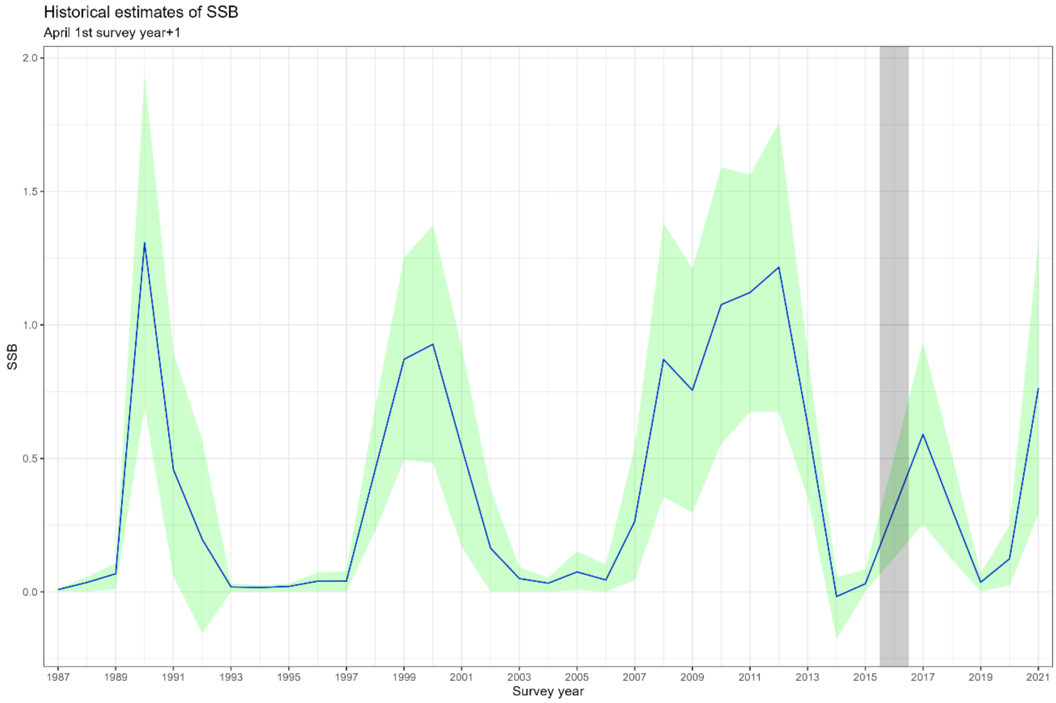


Figure 2. SSB from the new model. Shaded area shows 5–95% confidence interval.

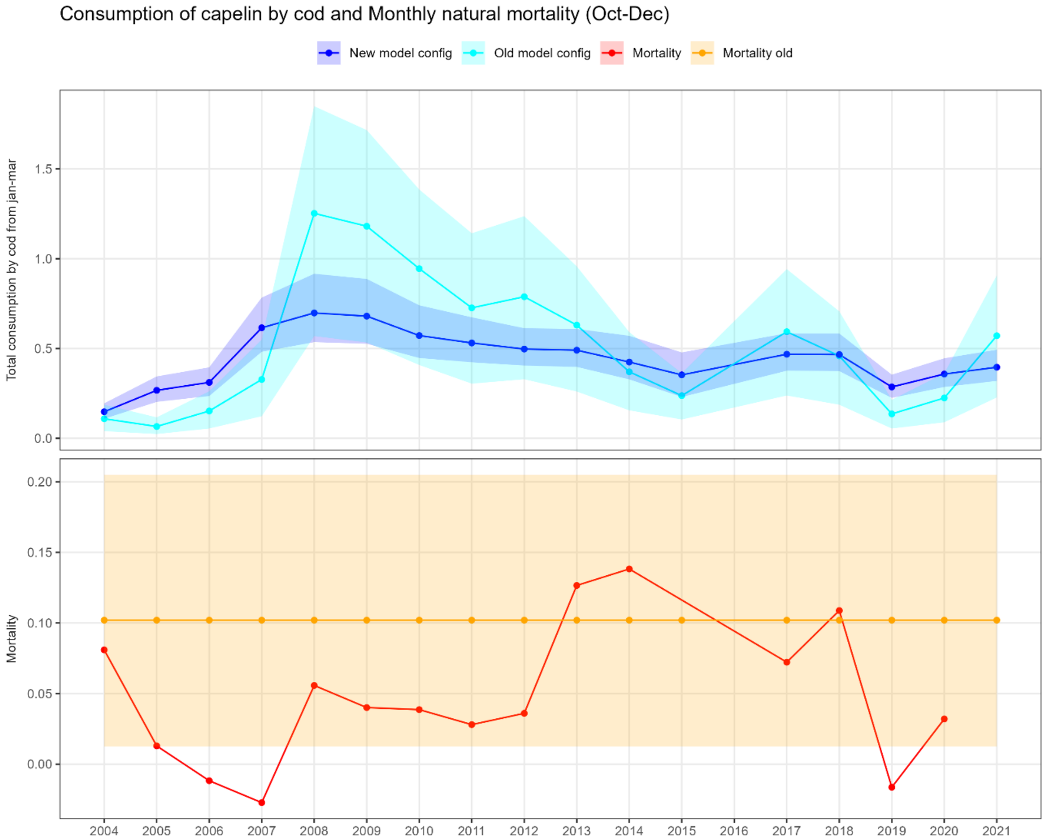


Figure 3. Comparison of consumption January-March (upper panel; median values and 5–95% confidence intervals based on 10000 simulation runs) and mortality October-December (lower panel) for new and old runs. In the lower panel, annual point estimates of autumn mortality using mortality from age 2 to age 3 as observed in the survey data are shown in red. The dark yellow line indicates average autumn mortality like it has been implemented up until present sampling from a selection of survey years, with light yellow color indicating the 5–95% confidence interval.

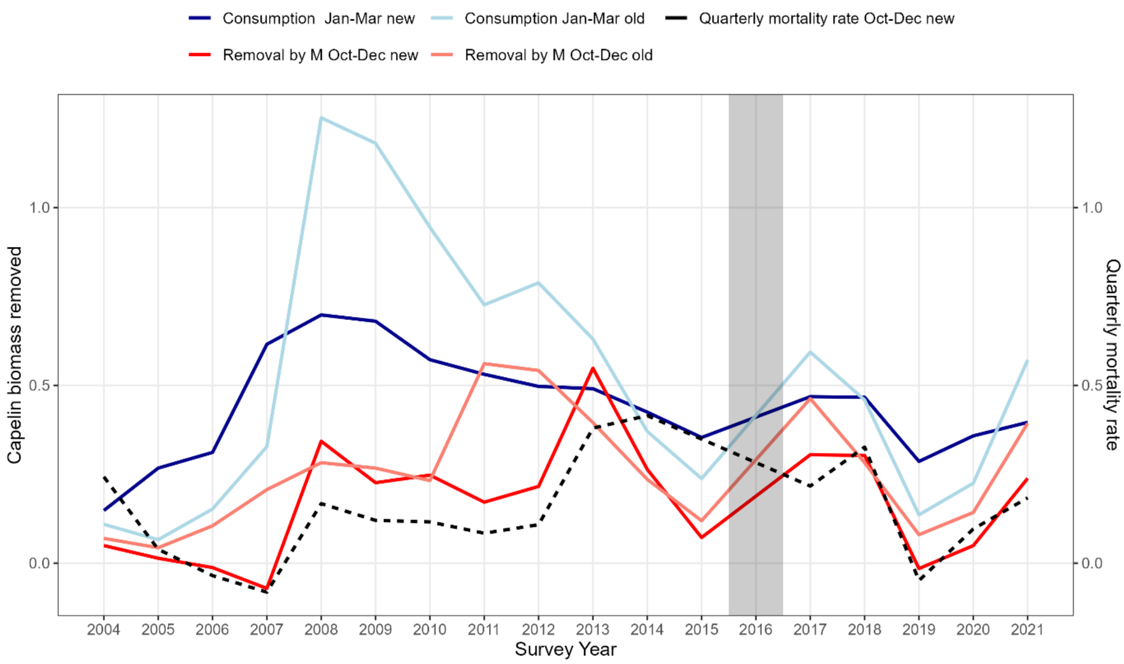


Figure 4. Capelin biomass removed by M (October-December) and predation by cod (January-March) for the old and new models for survey years 2004–2021, shown together with M values for October-December for the new model on a quarterly scale.

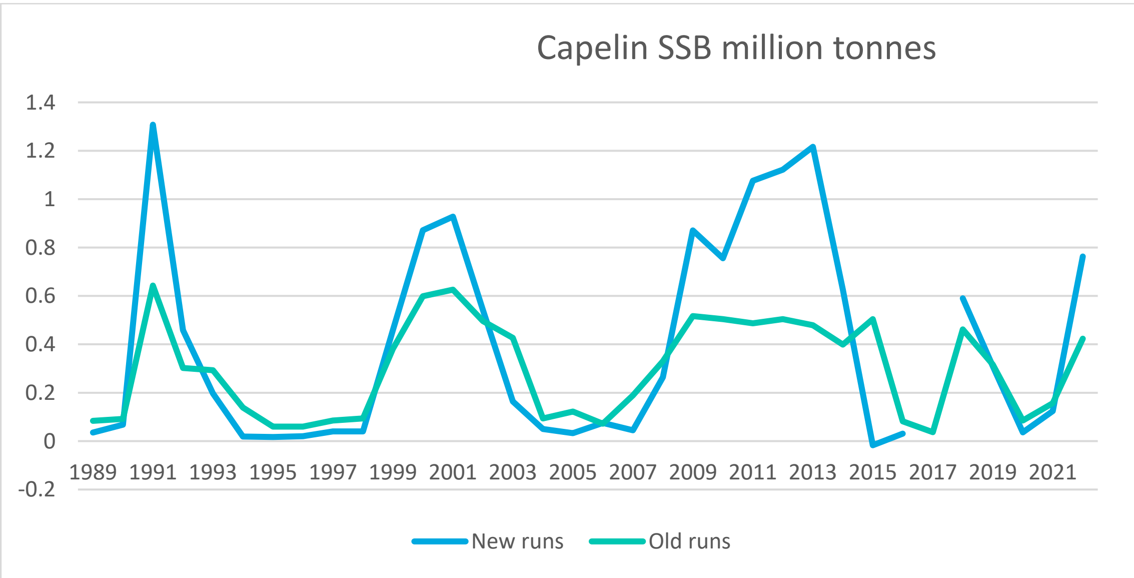


Figure 5. Capelin SSB with old and new model and data (median values).

2.1.8 Prediction into the future – input data including uncertainty assumptions

The benchmark group recommended to use the following parameter settings for future model predictions in the operational assessment:

-Time averaged (most recent 5 years) CV at age for the autumn survey, with the values not updated between benchmarks. If there is an expert judgement that the autumn survey is of unusually poor quality, then the annual CV estimates for that year should be considered. Strong effort should be placed on finding a precautionary method to use the annual CVs, as these account for poor survey years and would correctly allow for improvements in survey quality to be associated with increased catches.

Use a 14cm maturation length cut-off for all data and model.

- Mortality for October-December is based on survey mortality from age 2 to age 3. Values prior to 1988 (first capelin collapse) and 2015 and 2016 (poor survey year in 2016) are removed. Values to be used are drawn from the remaining years. Negative mortality values are included in the pool to draw from since it accounts for underestimation in the survey. M is estimated by comparing age 2 immatures and age 3 numbers from the same cohort.
- Mortality for January-March is estimated based on the following: Cod number, weight and proportion mature at age on 1 January is taken from the stock prognosis from the assessment made in the survey year, with uncertainty in numbers-at-age taken from the assessment model (issue with ages 3 and 4 as these are estimated by external recruitment model). No uncertainty on weight/maturation at age. Proportion of immature cod by age not overlapping with maturing capelin ("Svalbard component") is drawn randomly from survey data from the period 2014–2022, which are the years with most complete survey coverage.
- Fishing is assumed to occur in February-March only, with 30% of catches taken in February and 70% in March. All fishery is assumed to be on maturing capelin. No uncertainties are included here.
- Predation parameters (C_{max} and $C_{1/2}$) are taken from replicates from the new model estimates (see BS5 and BS7).
- Predation ability is assumed unchanged during the period January-March – previously M and F were applied monthly to reduce abundance – now mortality and growth are assumed to cancel out.

2.1.9 Basis for deciding on reference point; B_{lim} (BS8)

The rationale for the B_{lim} used currently for BS capelin is the following (Gjøsæter *et al.*, 2002):

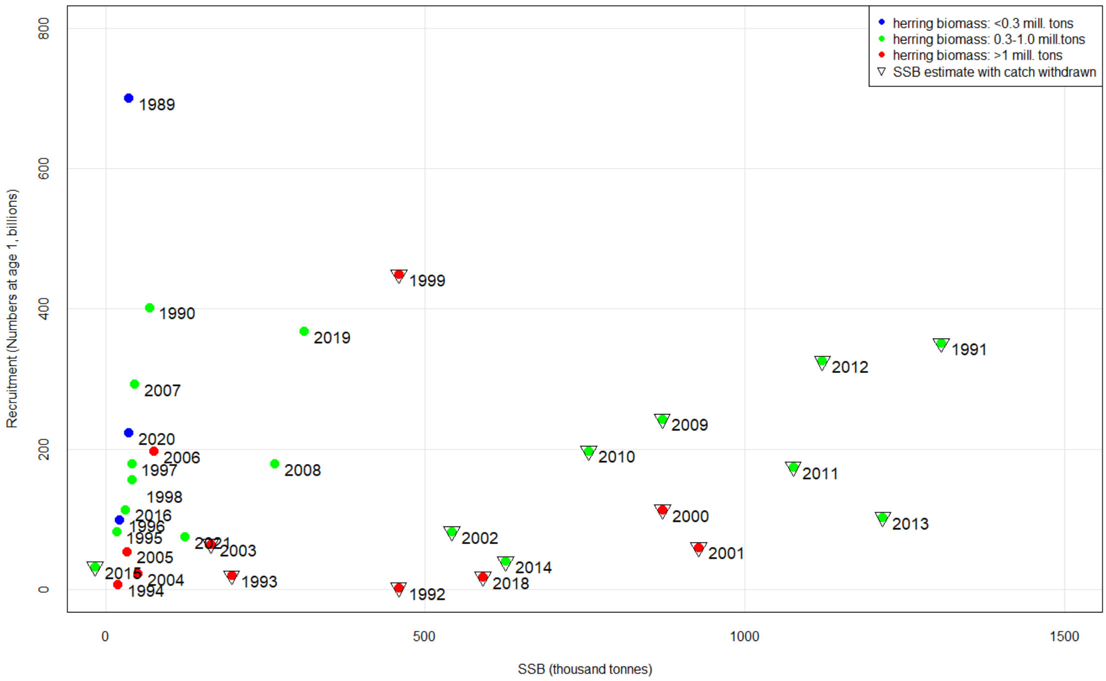
> **"For this stock, a B_{lim} equal to the 1989 spawning-stock biomass, which is the lowest SSB having produced an outstanding year class, at least after 1980, is considered a good basis for such a reference point in a non-herring situation. The median value of the 1989 spawning-stock biomass is 96 000 t. The assessment model may not yet account for all sources of uncertainty, and there are inconsistencies in the data series. Thus, it may be appropriate to use a somewhat higher B_{lim}. In recent years ICES has used a B_{lim} of 200 000 t."**

In BS8, an approach is suggested to take account for assessment uncertainty in the estimation of B_{lim}. A forecast is made from the survey year 1988, to 1 April 1989 using the Bifrost forecast model with standard parameterization except that a re-estimate of the 1988 survey biomass is used. The 95% upper confidence limit of the predicted spawning-stock biomass on 1 April is suggested as a basis for B_{lim}. The benchmark group did not recommend to account for uncertainty in the B_{lim}, since uncertainty is already accounted for in the harvest control rule.

During the meeting it was discussed whether the recruitment of the year class 1989 was a sound basis to use for estimating B_{lim}. It was agreed that this was an outlier in the time-series in terms of recruitment, and also that the good recruitment from this year occurred in a year with unusually low abundance of 0-group herring (the first strong year-class after the collapse; 1983-year-class, had left the Barents Sea in 1986 and no new strong year classes had arrived by then). SSB-recruitment plots excluding the early years with low herring abundance show that recruitment collapse can happen at any level of SSB, but good recruitment starts to appear from an estimated SSB of a little less than 100 000 tonnes. 1990 was the year with highest recruitment resulting from a low SSB, and it was recommended to use this year as the basis for B_{lim}.

After the meeting, new estimates of spawning-stock biomass were made based on the updated predation model and updated annual autumn mortalities. The new estimates are presented in an updated SSB-Recruitment plot in Figure 6. Herring biomass is calculated as the sum of biomass at age 1 and 2, where numbers of herring at age 2 is multiplied with mean weight of herring at age 2 and numbers of herring at age 1 in year y is calculated from abundance-at-age 2 in year y+1 assuming a mortality of 0.9. Numbers are from ICES (2022).

For the years with high maturing stock, the estimated SSB are considerably higher with the revised model than with the old model, while there is an opposite tendency for years with low maturing stock. Still, 1990 seems a good candidate to use for setting B_{lim}. The median SSB in 1990 with the present model run is 68 000 tonnenes. It was noted by the benchmark group that unaccounted uncertainties are associated with the estimates of SSB used as basis for the B_{lim}, both in the biomass estimation and the forecast. The managers must be aware of this when evaluating the reference point used in the harvest control rule.



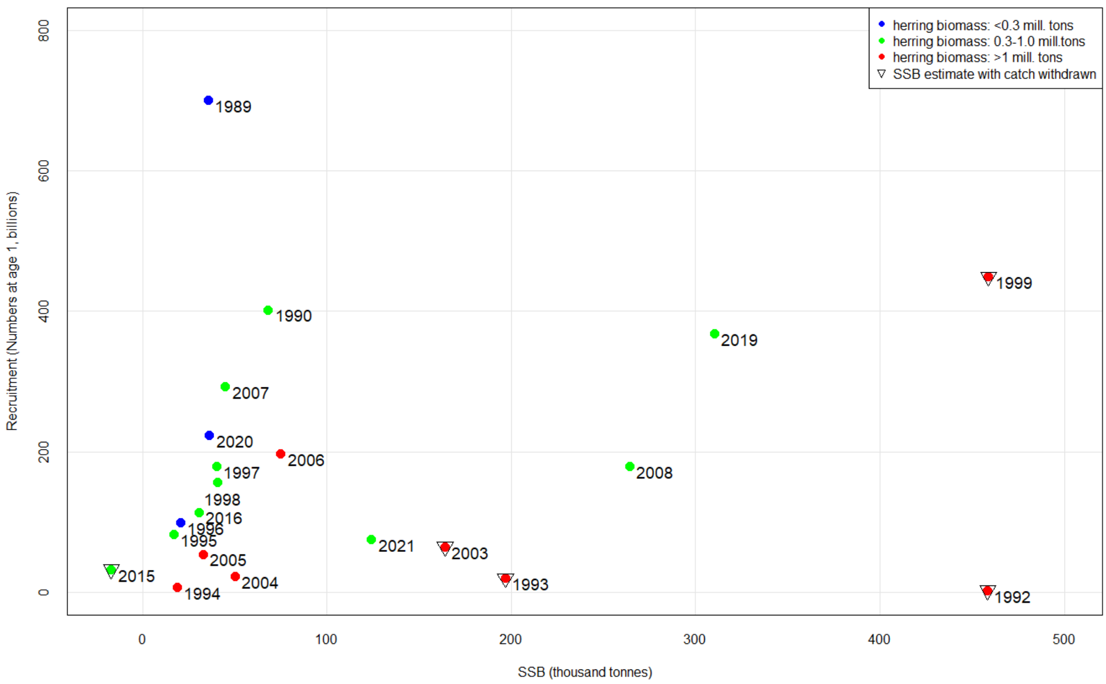


Figure 6. BS capelin recruitment (abundance-at-age 1) as a function of estimated spawning-stock biomass (SSB). SSB are estimates from the updated stock forecast model (median values). The years denote cohorts and different colors indicate biomass of young herring (age 1 and age 2) in the Barents Sea. Triangle marks year with catch, so catch is withdrawn in the estimation of the spawning-stock biomass. In the lower panel the SSB-R is plotted with x-axis truncated at 500 000 tonnes.

2.2 Harvest Control Rule (HCR) evaluation for the capelin escapement strategies

See section 4 below.

2.3 Future process and work

Short-term research recommendations were made for three topics related to the estimation of capelin biomass and associated uncertainty based on the BESS autumn survey.

The first topic was possible inclusion of swept-area estimates of capelin from demersal trawl hauls (BS1 and BS2). There was agreement that this capelin in principle should be included in the autumn estimate. There was also agreement that a method is needed to handle outlier samples (trawl hauls with very high catches). However, the method presented during the meeting was not accepted, and work to revise the method was recommended. A method for estimating uncertainty when combining the acoustic estimate and swept-area estimate is also required.

The second topic was related to the method for selection of biological samples (three different types of trawl sampling used in BESS) to acquire length distributions used for the acoustic estimate (BS3). The estimate is sensitive to the selection, and there was agreement that inclusion of demersal samples should be done with caution, but all relevant alternatives for selection were not presented for the benchmark meeting.

The third topic was how to implement uncertainty in the estimate of maturing capelin used for the prediction (BS3). In the present implementation, a fixed value of CV is used. During the meeting it was recommended that a 5-year-average be used as an intermediate step, but with a research recommendation to investigate the use of annual CV estimates.

These issues could be addressed during a review-type process as outlined in the new (2023) guidelines for benchmark processes. Such a review process addresses one or two larger issues and is carried out intersessionally between two expert group meetings but is not a full benchmark.

2.4 References

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Tjelmeland, S. 2002. A model for the uncertainty around the yearly trawl-acoustic estimate of biomass of Barents Sea capelin, Mallotus villosus (Müller). ICES J. mar. Sci. 59:1072–1080.

3 Iceland and Faroes grounds, East Greenland, and Jan Mayen area capelin

cap.27.2a514 – *Mallotus villosus* in subareas 5 and 14 and Division 2.a west of 5°W

The IEGJM capelin stock has been assessed by acoustic measurements in autumn and/or winter since 1980. From 1980–2015 the stock was manged by leaving 400 thousand tonnes for spawning. The method for setting the final TAC was not endorsed by WKSHORT-2009 because the value of M (natural mortality) used in the assessment calculations in the winter period (0.035 per month) was considered too low and uncertainty in the acoustic surveys was not included. Prior to WKICE-2015 a new advice framework based on a stochastic approach was developed and the management goal changed to leaving 150 thousand tonnes for spawning with 95% probability. The new advice framework was endorsed by WKICE-2015. The same advice framework was proposed at WKCAPELIN with 2 changes.

From 1990–2014 the same model for setting an initial, preliminary TAC had been used based on projection of survey estimates of immature abundance from the autumn survey in the previous year. That method was not endorsed by WKICE-2015 and a more precautionary method developed. In 2020 the management plan was changed so fisheries each season do not start until October 15th. At that time more recent information about the fishable stock are available and the TAC based on that information (intermediate TAC) replaces the initial, preliminary TAC before any fisheries start. Therefore, the method to set initial TAC was not discussed at WKCAPELIN.

3.1 The fishery

In the mid-1960s a purse-seine fishery began on capelin and soon expanded to a large-scale fishery. During its first eight years, the fishery was conducted in February and March on schools of prespawning fish on or close to the spawning grounds south and west of Iceland. In January 1973 a successful capelin fishery began in deep waters near the shelf break east of Iceland. In 1976 a summer capelin fishery began in the Iceland Sea. This fishery became multinational with vessels from Iceland, Norway, Faroes, and Denmark. The pelagic trawl was introduced to the fishery in the mid-1990s.

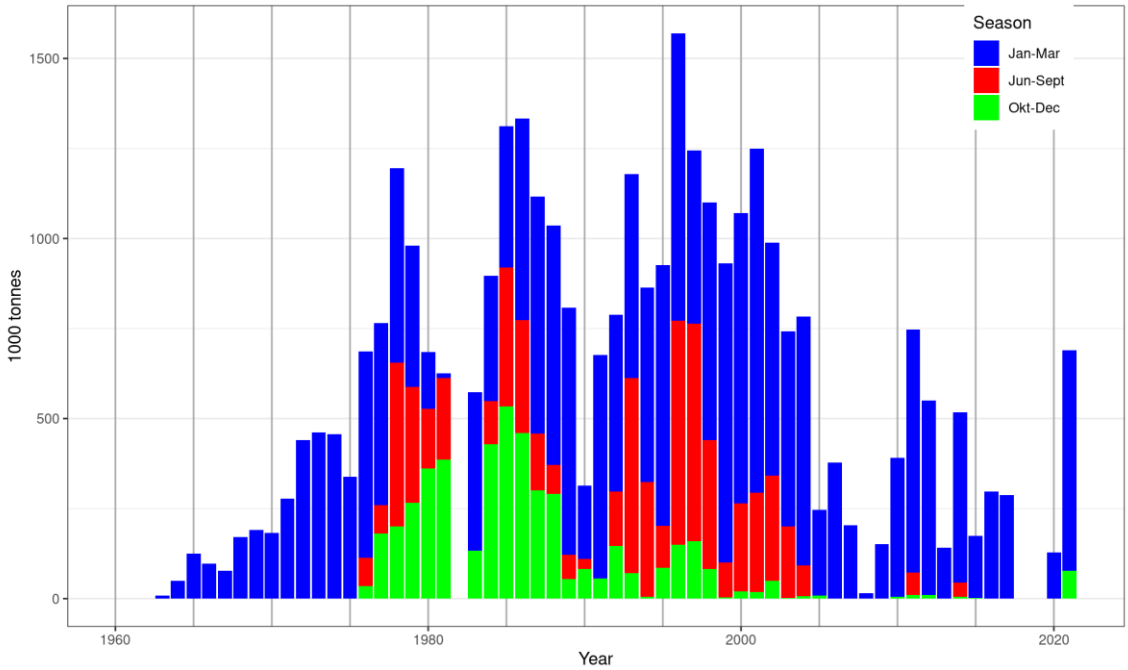

Figure 7.1.1. Total catch (in thousand tonnes) of the Icelandic capelin since 1963/1964 by fishing season. The year indicates former year of the fishing season.

A fishery during winter (January–March) has taken place in all years, with the exception of the winter of the1981/1982 ,1982/1983 ,2008/2009, 2018/2019 and 2019/2020 fishing seasons, when a moratorium was in effect (Figure 7.1.1). Until the late 1980s the fishery in October–December was much more pronounced than the fishery in June–September, whereas it was the opposite in the 1990s. During the 1990s the fishery in autumn was at low levels and practically no autumn fishery has taken place since 2000. Since the mid-2000s, a preliminary quota allowing for a summer fishery has only been set twice and the resulting fishery has been at a low level.

The fishing season was extended from June 20 to the end of the following March since the mid-1990s. However, when stock size has been estimated to be low the fishing season has started later, in October/November after an autumn survey, or even in January/February following a winter survey. In 2020 the start of the fishing season was changed and can at earliest start at October 15th.

3.2 Biological information

The timeline of life-history and survey events for a cohort of capelin can be summarized as follows (also see the schematic in Figure 7.2.1):

<u>Year 0</u>

- Spring: Hatches from egg.
- Summer: Larvae drift, from spawning locations, northwards to juvenile areas.
- Autumn: Observed in acoustic surveys, but not directly measured as 0-group, overlaps with immatures (age groups 1 and 2) and the mature/maturing stock.

<u>Year 1</u>

- Winter: Sometimes observed on the acoustic survey in northwest of Iceland as metamorphosing juveniles.
- Summer: The bulk of the cohort is still immature and sticks to the feeding areas.
- Autumn: Measured as immature. This measurement is the bases for Initial advice.

Year 2

- Winter: Immatures overlapping with the migrating mature capelin in parts of the areas covered acoustically.
- Spring: A relatively unimportant fraction appears to spawn as 2-year-old in some years.
- Summer: The bulk of the cohort is still immature but about to start maturation. The feeding migration begins.
- Autumn: September–October survey, the majority of the cohort is mature, but some may still be immature (delayed spawners). This measurement is the bases for Intermediate advice.

Year 3

- Winter: The bulk of the cohort migrate to spawn. The final TAC is issued in-season, based mainly on acoustic estimates of this cohort.
- Spring: Spawning and subsequent mortality.
- Autumn: The rest (minority) of the cohort (that did not spawn in spring) is measured acoustically.

Year 4

- Winter: The rest of the cohort is measured acoustically when migrating to the spawning grounds.
- Spring: Spawning and subsequent mortality.

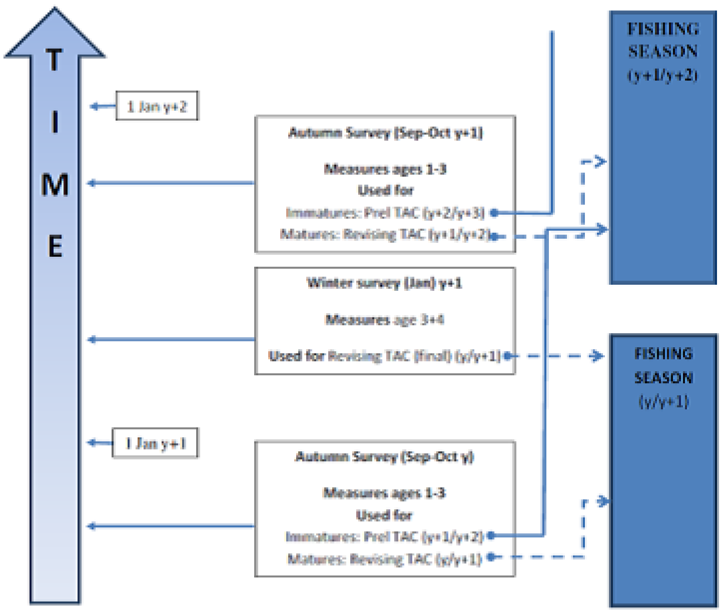

Figure 7.2.1. Timeline for surveys and their use in TAC setting. Solid line on the left side of the diagram marks the time when the survey takes places and the place of 1 January on this timeline. The solid line on the right hand side of the diagram marks the setting of the preliminary TAC while the dashed lines mark revisions of the TAC.

3.3 Stock structure

Capelin is a small pelagic schooling fish. It is a cold-water species that inhabits arctic and Sub-arctic waters in the North Atlantic and North Pacific. Capelin in the Iceland-East Greenland-Jan Mayen area is a separate stock.

3.4 Stock assessment

The stock assessment model for IEGJ capelin is in principle simple. It is assumed that $q = 1$ in January surveys. The official assessment value is biomass of mature capelin January 15th, both average value and uncertainty. More detailed description of the assessment and management is in working documents I01–I07.

In many fishing seasons, a number of acoustic surveys is conducted, always one in the autumn and in most years one or more in the winter. Figure 1.4.1 clearly indicates there is a worse relationship between autumn and winter surveys after 1991/92 than before. The assessment is like many other assessments based on the weighted average of one or more surveys.

The acoustic surveys are very sensitive to timing of both autumn and winter surveys.

The winter surveys must be conducted after the mature stock enters the Icelandic continental shelf north of Iceland and before they migrate into the warm sea southeast of Iceland when they take the usual eastern route clockwise around Iceland to the spawning areas in the south and west. The timing of the migrations varies, and in some years the first schools have migrated into the warm sea (where acoustic measurements are unreliable) before the last schools enter the continental shelf. Identifying which capelin has not been measured before can often be done, the main assumption is that capelin found in the northeast, east, and southeast of Iceland are stationary or migrating clockwise towards the spawning areas.

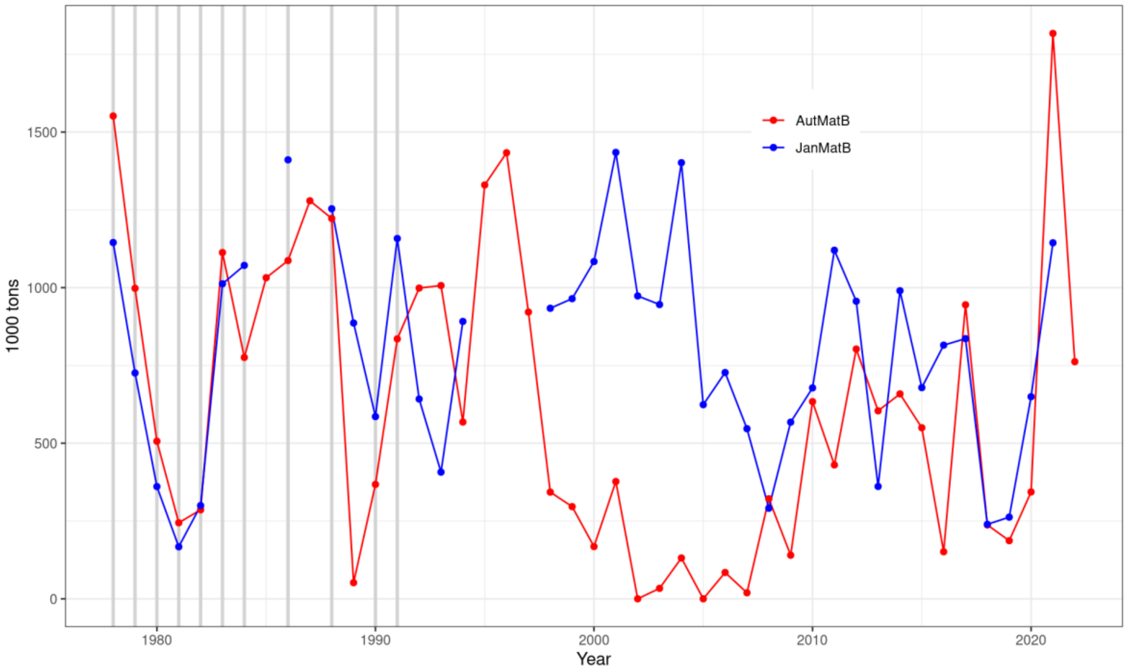

Figure 1.4.1 Biomass of mature capelin in autumn (red) and winter surveys (blue) corrected for catches taken between surveys. The grey vertical lines indicate years used to infer the relationship between the surveys on which M=0.035 per month was estimated.

When to take the average of surveys or let the highest value stand alone is always a matter of judgement. Estimated CV, age composition and spatial distribution compared to older measurements help in the decision-making.

Timing issues are also important in the autumn surveys. The capelin migrate north to 70th degree or further to feed, and return back in October-January, the tendency has been that they return later. After 2000 only part of the mature stock was covered in the autumn surveys (figure 1.4.1), the main reason was problems with drift ice in areas inhabited by capelin. Insufficient funding to cover the distributional area did also matter, limited funds were not spent on survey with variable coverage. After 2009 the survey area was increased to the north, but areas close to Greenland could not be covered due to ice. Therefore, the autumn survey was moved from October to September in 2013.

There are at least 3 advantages of autumn surveys compared to the winter surveys.

- The surveys are not conducted in a period of active migration so disruption due to weather is not as much of a problem.
- TAC is issued earlier so companies have longer time to prepare for the fishing season.
- Safety if winter surveys fail for example due to bad weather.

Since the new assessment method was introduced in 2016 the final assessment has been based on one or more surveys. In the winter, each survey is often "one weather window" and after that combined with another survey in another "weather window". Autumn surveys have been combined with winter surveys in a similar way as different winter surveys have been combined, based on an observation from 1980–1992 that autumn and winter surveys lead on the average to similar biomass (Figure 1.4.1) . When used in assessment CV of autumn surveys is to account for longer period, increased by multiplying with a stochastic factor ($\mu \approx 1, \sigma \approx 0.3$) as described in WD14 from WKICE-2015 and the stock annex.

The intermediate assessment conducted in October is based on prediction that the biomass of mature capelin on the 15th of January next year will on the average be the same as in the autumn survey.

Changes to the assessment discussed at WKCAPELIN2 2022 were related to uses of the autumn survey in the assessment and winter surveys conducted outside the normal period and areas. Changes in the use of autumn surveys originated from the discrepancy between the autumn 2021/winter 2022 pair that was unique but a similar issue might happen again in near future (see WD I01):

1. Autumn survey biomass for use in assessment will be compiled by reducing number-at-age by M=0.035/month, multiplying by mean weight at age of same yearclass in winter. Earlier the autumn survey biomass was used unchanged in assessment as from 1980–1992 the reduction in numbers and increase in mean weight at age approximately cancelled each other out. The weight increase has been less in recent years and time between autumn and winter surveys is longer so applying a monthly M was deemed appropriate.
2. Autumn survey has a maximum weight of 1/3rd in the final assessment. No such limit was in the assessment adopted by WKICE 2015.
3. Age distribution in the autumn and winter surveys will be compared, and the autumn survey will be correct for any discrepancy if required (see WD I01)
4. Acoustic surveys in the warm sea are not included in the assessment (see WD I01)
5. Acoustic surveys late in the season north and northwest of Iceland late in the season are not included or added to previous surveys except if a large part of the total stock is found there. See (WD I01 and I03)

Of those changes only #2 was adopted by the benchmark.

As before, all combinations of surveys are done by adding replica by replica.

The final assessment is compiled as stochastic replicas of the mature part of the stock at January 15th. It was discussed at the meeting not to use the estimated CV of the final assessment for prediction but rather use CV of 0.2 done by scaling the spread of bootstrap value to reach that goal. Similarly, a CV of 0.25 could be used for the intermediate assessment (see WD I02). This change can be advantageous when the final acoustic measurements are based on a large stock distributed over a large area i.e low CV. It was however, not adopted during WKCAPELIN 2022.

Going to a fixed CV was not accepted by MRI staff as discussed at a meeting on March 4th. Another ICES Working Group (WKSHORT 2009) rejected the assessment method as CV in surveys was not considered. Many of the surveys, especially in the winter have high CV and would lead to too high advice if that is not taken into account. At the March 4th meeting the current methodology (use bootstrap replicas from each survey) was accepted, but it was recognized that a floor on CV of the final assessment might be needed.

Each year's assessment is introduced and reviewed at the meeting of ICES Northwestern Working Group in April-May. The review is in some sense too late but could point to things to avoid in future assessments. WKICE 2015 discussed more involvement of ICES in the final advice that is often given a few days after the final acoustic measurement.

3.5 Prediction model

The final assessment is projected from 15th of January to 15th of March using the predation model described in WD I03 and the catches that are adjusted until $P(SSB < B_{lim})=0.05$. This approach is unchanged from what was decided at the 2015 benchmark assessment.

3.6 Reference points

The only reference point needed for IEGJ capelin is B_{lim}. B_{lim} was set to 150 thousand tonnes in WKICE 2015 based on the average of the 3 lowest values of spawning stock, occurring in 1981, 1982 and 1990, which all lead to average recruitment. Before WKCAPELIN 2022 the spawning stock since 1981 was recalculated using the prediction model adopted in 2015 and recalculated indices from acoustic surveys from 2002–2006. (Working document I04). The recalculated stock – recruitment plot indicated that basing B_{lim} on the same 3 years was appropriate, giving a B_{lim}=114 thous. tonnes.

3.7 Management plan

The management plan is based on the criterion $P(SSB < B_{lim}) < 0.05$. SSB is obtained by projecting the stock forwards with the predation model.

Intermediate advice is calculated based on the intermediate assessment and the same criterion as described in the stock annex. Change from what was adopted in the benchmark 2015 is that the intermediate advice is now only 2/3rd of the calculated value. It was 100% according to the 2015 benchmark.

In 2020 the coastal nations agreed that fishing in each season should not start until October 15th.

Before the meeting, the advice on TAC according to the new advice framework was compiled and compared to the old advice framework for the years 1981–2015. The results show that the current method is more precautionary (WD I04).

No changes are suggested for the current management plan regarding how the preliminary advice and final advice are derived. Since the beginning of the fishery was changed to October 15, the intermediate TAC will now supersede the initial TAC when fisheries start.

3.8 Conclusions

WKCAPELIN accepted the assessment methodology for IGJM capelin, as described in the stock annex in this report, as a benchmark assessment.

3.9 Harvest Control Rule (HCR) evaluation for the capelin escapement strategies

See section 4 below.

3.10 Recommendations

Work that has been started in Iceland and Norway to get better information on the TS value of capelin, both average values and variability, should be continued. (WD I05). Equipment to conduct this analysis is now available in both countries, the problem is to get enough vessel time. These analyses are really a prerequisite for doing work on the importance of capelin in these two ecosystems. They are also perquisites for improving the predation models used in the capelin management.

Along the same track, try to match catches and NASC value of capelin for vessels fishing capelin with pelagic trawls. (WD I06).

Work presented for the Barents Sea capelin stresses the importance of capelin as a keystone species in the ecosystem, and also suggests that capelin should be fished as close to spawning as technically and economically possible.

Research on the role of capelin as predator and prey, in the Icelandic Sea ecosystem should be directed to the main feeding period in May -July where limited data exist.

Marine mammal abundance in the capelin distribution areas should be monitored, e.g. by including observers on autumn surveys every year. Such a program could indicate whether predation on capelin by whales in quarter 3 should be added to the advice-framework.

Further work on the new framework for setting the advice is needed, including detailed examination of the series of historical bootstrap estimates and additional tests of the predation model by cod, haddock and saithe, based on the groundfish survey in March (IGFS) data.

More detailed stomach content analysis should be conducted in the groundfish survey in March to identify to what extent capelin that has already spawned is eaten.

Predation by humpback whales in quarter 1 should be investigated but increased number of them are following the capelin spawning migration according to captains of capelin vessels.

The design of acoustic surveys should be studied further, and collaboration with industry that has been ongoing should be continued and further developed. Part of this work would be to investigate when it would be appropriate to measure separately dense schools of capelin (biasvs.variance problem).

Pairs of successful surveys should be identified and examined to determine the correspondence between September–October and following January–February surveys to potentially shed light on natural mortality, especially if supplemented with research on survey catchability and target strength.

Further work on survey stratification and comparison with alternative approaches to estimate uncertainty could also usefully be undertaken, e.g. using geostatistics. Alternative approaches to estimate uncertainty could lead to different survey design.

Coordinated collection of biological samples and logbook information from non-Icelandic vessels should be initiated, to ensure broader coverage of participants in the fishery.

3.11 Working documents

- I01. Capelin data and advisory process. Overview. (I01_Overview.docx)
- I02. Cofficient of Variation of Surveys. (I02_CVSurveys.docx)
- I03. Description of the predation model. (I03_PredationModel.docx)
- I04. Calculations of the spawning stock from 1981–2022, estimation of Blim and advice given by the new HCR from 2015. (I04_HistoricalSSBandBlim.docx)
- I05. Re-evaluation of the target strength and the acoustic properties of the capelin stock in the Iceland-East Greenland-Jan Mayen area. (I05_TS_Benchmark.docx)
- I06. Capelin fisheries in the Iceland-East Greenland-Jan Mayen area.
- I07. IEGJ capelin. Experience with new management plan 2015/16 to 2021/22.

3.12 References.

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ICES 2015. Report of the Benchmark Workshop on Icelandic Stocks (WKICE), 26–30 January 2015. ICES Headquarters. ICES CM 2015/ACOM:31.

Vilhjálmsson, Hjálmar. 1994. "The Icelandic Capelin Stock: Capelin, Mallotus villosus (Müller) in the Iceland–Greenland–Jan Mayen area." Rit Fiskideildar 13: 1–281.

4 Harvest Control Rule (HCR) evaluation for the capelin escapement strategies

Escapement strategies are HCRs which are suitable for stocks with highly variable stock size and recruitment, allowing for high catches in good years while protecting the stocks in poor years. The standard format for such a rule would be for the spawning stock to be "95% likely to remain above B*escapement* after the catches are taken", where B*escapement* is the biomass of adults allowed to "escape" the fishery and survive to breed. For fish such as capelin, where there is a high spawning mortality, B*escapement* may be set to B_{lim}. In this case, both the Barents Sea and IGJM rules are in this form, and are both based on HCRs previously adopted by ICES. The meeting was tasked with evaluating if the existing HCRs continued to be precautionary, and therefore could continue to be used as the basis of ICES advice.

The success of any such escapement HCR rests on the stock estimate being unbiased, the uncertainty of that estimate being correctly characterized, and the estimated B_{lim} being accurate. None of these three things can be guaranteed, and would need a more detailed investigation to conduct a full MSE. However, the work at this benchmark has followed standard ICES practices, and by including predation mortality in an attempt to avoid biases from that source the work here is more detailed and realistic than in many cases. The uncertainty estimates are the best available and B_{lim} has been derived following ICES procedures, although (as is always the case within ICES) no estimate of uncertainty has been placed on this estimate. The workshop therefore evaluates that the approach taken represents best available science following ICES procedures. The two HCRs are therefore considered as precautionary as is typical for any ICES escapement strategy. Furthermore, the HCRs have functioned successfully for a number of years (since 1991 for Barents Sea, and since 2015 for IGJM). Provided no significant change is made to the HCR or to the performance of the underlying models, the rule should continue to be as precautionary as previously.

For IGJM capelin the entire model has been revised downward with the inclusion of predation mortality, and the reduction in B_{lim} (from 150kt to c. 110kt) is in line with the reduction in the model biomasses. Thus, the B_{lim} is largely unchanged relative to the estimated biomasses in the model. In the Barents Sea the year used as basis for the B_{lim} has changed, but the absolute value of the estimate is very close to that used previously. Therefore, in both cases the revisions in the underlying models are considered not to have significantly affected the performance of the HCRs.

However, in the Barents Sea the existing HCR contains a precautionary buffer within the B_{lim} that will be avoided in the HCR. This precautionary buffer lifts the B_{lim} value from just under 100kt to 200kt. This inclusion of a precautionary buffer in B_{lim} is not standard ICES procedure and should not be continued. The WKCAPELIN workshop therefore proposes a revised B_{lim} directly based on lowest observed SSB which led to good recruitment, with no precautionary buffer. However, the workshop was also tasked with evaluating the precautionary nature of the existing HCR (with the buffer), and did not examine an alternate formulation without the precautionary buffer. The workshop therefore recommends that the HCR be re-worded to require that the stock after fishing should remain above B*escapement* rather than above B_{lim}, and that the B*escapement* remain at the existing 200kt. This would ensure that the HCR is worded in terms of modern ICES procedures, while meeting the goal here of evaluating the existing HCR as remaining precautionary. It may be that a HCR with a lower B*escapement* (potentially set at the actual B_{lim}) in the Barents Sea would also be precautionary, however this was not evaluated at this meeting and would require a specific HCR evaluation.

With the above amendment to the Barents Sea HCR wording to fit with modern ICES terminology (and with inclusion of the existing precautionary buffer in the $B_{escapement}$ rather than B_{lim}), WKCAPELIN therefore concludes that both HCRs remain precautionary and that ICES can continue to give advice on this basis.

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Annex 2: Resolutions

2021/2/FRSG25 The **Benchmark workshop on capelin (*Mallotus villosus*)** (WKCAPELIN 2022), chaired by Hannah Murphy, Canada, and Daniel Howell, Norway, and attended by invited external experts Alejandro Buren, Canada, and Mathieu Boudreau, Canada, will be established and meet online 30 November–2 December 2021 for a data workshop (DWK), and at MFRI, Hafnarfjörður, Iceland on 21–25 November 2022 for a benchmark meeting. WKCAPELIN 2022 will work to:

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

- i. Stock identity and migration issues;
- ii. Life-history data;
- iii. Fishery-dependent and fishery-independent data;
- iv. Further inclusion of environmental drivers, multispecies information, and ecosystem impacts for stock dynamics in the assessments and outlook;

Agree and document the preferred method for evaluating stock status and (where applicable) short-term forecast and update the stock annex as appropriate. Knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated into the methodology If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

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

Develop recommendations for future improvement of the assessment methodology and data collection;

As part of the evaluation:

- i. Conduct a three-day data workshop (DWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;
- ii. Following the DCWK, produce working documents to be reviewed during the Benchmark meeting at least seven days before the meeting;

f) Evaluate whether the current harvest control rules are precautionary in light of potential acceptance of alternative model formulations and reference points from the benchmark.

Stock or issue	**Stock category and methods**
cap.27.2a514 – Capelin (*Mallotus villosus*) in subareas 5 and 14 and Division 2.a west of 5°W (Iceland and Faroes grounds, East Greenland, Jan Mayen)	1 – HCR based on survey SSB estimates.
cap.27.1-2 – Capelin (*Mallotus villosus*) in subareas 1 and 2 (Northeast Arctic), excluding Division 2.a west of 5°W (Barents Sea capelin)	1 – HCR based on survey SSB estimates.

Annex 3: Barents Sea capelin – Working documents

Number	Title	Authors
BS0	Description of capelin biomass estimation from BESS surveys	Georg Skaret *et al*.
BS1	Swept-area estimation from bottom trawl - method	Are Salthaug *et al*.
BS2	Swept-area estimation from bottom trawl - application	Harald Gjøsæter *et al*.
BS3	Abundance estimation from autumn survey - Selection of stations for allocation and survey CV	Georg Skaret
BS4	Spawning survey – summary of results and suggestion for application	Georg Skaret *et al*.
BS5	Cod consumption – description of assumptions and data	Bjarte Bogstad
BS6	Basis for the estimation of autumn mortality	Georg Skaret *et al*.
BS7	Predation model – description of model and simulation runs	Magne Aldrin *et al*.
BS8	Basis for deciding on reference point (B_{lim})	Georg Skaret *et al*.
BS9	Maturation model	Bjarte Bogstad *et al*.
BS10	Estimation of maturity parameters based on catch data	Sondre Hølleland

Barents Sea capelin assessment - Estimation of abundance and biomass

Georg Skaret, Dmitry Prozorkevich, Bjarte Bogstad, Harald Gjøsæter

Abstract

The most important input to the Barents Sea capelin (BS capelin) stock assessment is the acoustic estimate of biomass and abundance in the autumn. Since 2004, this estimate is based on capelin monitoring as part of the comprehensive annual Barents Sea Ecosystem Survey (BESS). In the present document, we describe in detail how the survey coverage has been and how estimation has been done during the period 2004-2021. We give extra attention to the biological sampling and allocation and weighting of biological samples in the estimate since the calculations are sensitive to this and the procedure followed here is not fully standardized. Since 2016, the annual estimation has been made using the new software StoX where measures of uncertainty like sampling variance can be readily estimated. We suggest that instead of the presently used fixed CV by age of 0.2 in stock projections for the capelin assessments, estimates of sampling variance from the most recent capelin monitoring should be applied. We also present a re-estimation of the BS capelin stock from 2004-2015 using StoX and a comparison of output with the original estimates from the BEAM software. In the StoX-framework both input data, assumptions and calculations are available for future analyses, and sampling variance can be estimated in a simple manner. Comparison of the results show that the output from the two estimation softwares are similar.

Background

Estimates of Barents Sea capelin stock abundance are made annually based on acoustic-trawl monitoring data from the joint Russian/Norwegian Barents Sea Ecosystem Survey (BESS) conducted in August-October. In the Barents Sea capelin stock assessment, the BESS acoustic-trawl estimates are interpreted as absolute abundances and they are the only capelin stock abundance input data used in the assessment.

Method

Design of the survey and coverage

BESS is a multi-purpose ecosystem survey which started in 2004 and then incorporated several past survey efforts including a capelin monitoring survey. The BESS survey design and sampling tactics therefore reflect compromises between the different purposes of the survey (see e.g. Eriksen et al. 2014). The collection of acoustic data up until 2015 did not follow a specific design as such with regards to the acoustic data collection. This is particularly clear for the years 2004-2008 (see Figure 1). Gradually, BESS converged towards a sampling design with a uniform grid of sampling stations, and from 2009 onwards the transects reflect the necessity to efficiently connect the fixed grid stations, and therefore often end up as equally spaced parallel transects (Figure 1 and Figure A1). From 2016 onwards, the acoustic data collection in the main capelin distribution area followed a classic transect-based stratified sampling design with systematically spaced parallel transects (Jolly and Hampton, 1990; Figure 1). In practice, the starting points must also be considered to be random since the geographical positions of the stations are independent of the underlying distribution of the capelin (Simmonds & Fryer 1996, Tjelmeland 2002). The entire distribution area of capelin has been assumed to be covered in all years except for 2014, when ice covered some of the typical capelin distribution areas in the north. In addition, the NASC distribution (Figure 1) suggests that capelin distribution extended north of the covered area also in 2008 and 2011.

Acoustic data collection and processing

Acoustic equipment

Simrad EK60 echo sounders have been used for acoustic data collection during most of the BESS surveys for 2004-2021. However, in the start of the series, Simrad EK500 echo sounders were used. The EK500 were replaced with EK60 echo sounders in 2005 on board RV 'Johan Hjort', and in 2008 on board RV 'Helmer Hanssen' (previously named RV 'Jan Mayen'). On board the RV 'Vilnyus', RV 'Fridtjof Nansen', RV 'Smolensk' and RV 'Atlantniro' EK60 has been used after 2004. The rental vessels F/V 'Eros' in 2016 and 'Christina E' in 2011 also used EK60 echo sounders. Since 2017, 'G.O Sars' and 'Johan Hjort' have used the Simrad EK80 broadband echo sounders, but they have been operated in 'EK60-mode'. Helmer Hanssen have used EK60 echo sounders.

The echo sounders are mounted on retractable centreboards on board 'Johan Hjort' and 'G.O Sars', and since 2008 on board 'Helmer Hanssen' in order to reduce the signal loss due to air bubbles close to the surface. On board the 'Vilnyus', 'Fridtjof Nansen', 'Smolensk' and 'Atlantniro', the echo sounders are mounted on the hull.

Processing of acoustic data

The Large Scale Survey System (LSSS, Korneliussen et al. 2016) is presently used for processing of the acoustic data on board. Previously, the processing was done using the Bergen Echo Integrator (BEI, Knudsen 1990). LSSS replaced BEI in 2007 on board 'G.O Sars' and 'Johan Hjort', and in 2008 on board 'Helmer Hanssen'. Prior to 2014, the FAMAS software (Nikolaev et al., 2000) was used onboard RVs 'Vilnyus', 'Fridtjof Nansen' and 'Smolensk'. The acoustic recordings are displayed in echograms on computer screens and during processing noise is first removed and bottom detection line adjusted to not include contribution from bottom echo. Then the backscatter is allocated to species based on catch composition in the trawl (pelagic and demersal hauls), the appearance of the echo recordings, inspection of target strength distributions and inspection of target frequency responses.

After the processing, the data are stored to a database at 10 m vertical resolution and 1 nautical mile (nmi) horizontal resolution (the resolution has varied some through the time series) in units of nautical area scattering coefficient (NASC; m^2/nmi^2).

Collection and processing of biological data

Three types of trawl hauls which all sample capelin are carried out during BESS:

1) From 2005, 15 minute demersal hauls at fixed positions using Campelen 1800 shrimp trawls with a vertical opening of 3.5-4 m.
2) 0-group hauls at fixed positions (same positions as the demersal hauls) using Harstad-trawl with a ca. 20x20 m opening. The trawl is deployed stepwise in depths of 0, 20 and 40 m with 10 minute sampling at each depth. More depths can be included if the acoustic recordings indicate 0-group fish deeper down.
3) Target hauls at non-fixed positions on acoustic recordings using Harstad-trawl.

From all trawls, length and weight are measured (catch size permitting) for 100-300 capelin, and samples of age, sex, stomach fullness and maturity stage are taken from 25-50 fish from the trawl hauls.

The capelin length distributions are different for the various trawl hauls (see fig. 3), and they are assumed to not be equally representative of the length distribution in the local part of the capelin population registered by the echosounders. For the biomass estimation in StoX, this is handled by weighting of the hauls according to the NASC in a radius of 10 nautical miles around each trawl station. This is done by combining the NASC-values with the length distribution of a given biotic station to calculate a density as number per square nautical mile which is used as the weighting variable for each trawl station. An example figure with the circle size proportional to the weighting is given in Fig. 2. If capelin has been recorded acoustically in a stratum, but no capelin biological samples from trawl hauls exist for that stratum, stations from adjacent strata are used for the conversion of NASC to density.

Estimation of abundance and biomass
Based on the output from the acoustic processing in the quantity of NASC, the density of targets (ρ_a) – in this case capelin, can be calculated according to:

$$\rho_a = s_A / \{4\pi \langle \sigma_{bs} \rangle \}$$

where σ_{bs} is the expected backscattering cross-section of one single target. σ_{bs} is determined indirectly from the size distribution of fished samples, and an empirical equation relating the target strength (TS) to fish length. For Barents Sea capelin, TS is assumed to relate to fish length (L) according to (Dommasnes & Røttingen 1985):

$$TS = 19.1 \cdot logL - 74$$

TS is related to σ_{bs} as:

$$TS = 10 \cdot log10(\sigma_{bs})$$

For the conversion of NASC to capelin abundance and biomass in the estimation, trawl hauls within a given stratum have been used. There is no standardised method for how trawl hauls are included as will be further described in the following section.

Capelin biomass estimation using StoX (2016-present)
From 2016 to present, we have used the software StoX (Johnsen et al. 2019) to estimate capelin abundance and biomass with associated sampling variance (survey CV). StoX version 2.7 and Rstox 1.11 have been used. R for Windows version 3.6.1 have been used in the R calls (https://www.r-project.org/).

The principles described in the section above are used for the estimation, but the actual steps in the estimation are listed below here. Only StoX-processes (process names marked in blue) which are related to the abundance estimation are listed below (StoX-processes, which are related to data reading, filtering and organising are not listed).

1) StationLengthDist Recalculate capelin length distribution per station to percent length distribution

2) MeanNASC Calculate arithmetic mean NASC per transect with transect defined as the Primary Sampling Unit (PSU)
3) BioStationAssignment Assign the biological stations to strata
4) BioStationWeighting Weight the output from 1) according to NASC in a radius of 10 nautical miles
5) TotalLengthDist Use the assignment and weighting in 3) and 4) to produce length distributions per stratum
6) AcousticDensity Use the length distributions from 5) and the mean NASC from 2) to calculate fish densities per square nautical mile per length group and per transect
7) MeanDensity_Stratum Calculate mean fish density per length group and per stratum based on 6) with each transect weighted according to its length
8) Abundance Multiply the fish density of each stratum from 7) with the area of a given stratum to produce abundance per length group per stratum.
9) SuperIndAbundance Allocate the abundance per given length group and stratum from 8) equally to each fish in the given length group and stratum which holds individual data (i.e. age, sex, maturity state, stomach fullness). Each of these 'superindividuals' with associated abundance are then used to estimate population parameters like abundance at age and sex.
10) FillMissingData Fill in population parameter values for the super individuals from 9) that do not have an associated age. The filling is based on a search for other super individuals within the same length group, estimation layer and station which has an associated age. If such super individuals are found, one of them is randomly selected and parameter values for age, weight, sex, maturity state and stomach fullness are allocated to the super individual that did not have any associated age-value. We chose imputation by age since aged individuals in the data material are also associated with other individual parameters. Only the population parameters that are lacking, are imputed, no existing parameters are replaced.
    If no adequate individuals are found in the first round of search, a new search is done on a stratum resolution, or finally, on a survey resolution (all strata).

In the following we describe specific settings in StoX which were applied and are relevant for the biomass estimation. Again, StoX process names are marked in blue, parameter names of a given process in **bold**, and parameter settings in *italic*.
In the process FilterAcoustic, the parameter **FreqExpr** was set to *frequency=38000* to indicate that 38 kHz acoustic data are used, and for the parameter **NASCExpr** *acocat == 16* to indicate the acoustic category corresponding to capelin.
In the process NASC **LayerType** was set to *WaterColumn* to indicate integration over the entire water column.
For the process FilterBiotic there is a parameter **FishStationExpr** where stations to be included in the estimation are selected. For the BS capelin estimation the inclusion of stations varies somewhat from year to year. This is described further in BS3 in the appendix of the present report. As an example we can set *gear!~['3270','3271'] || station == 543 || platform == 5481* to exclude all demersal trawls except the specific trawl station number 543 or if the demersal trawl was conducted on board the vessel 'Vilnyus' (platform 5481). For the **CatchExpr** in the same process we set *noname == 'lodde'* to include only samples with capelin and for the **SampleExpr** we set *group!~['10', '49']* to filter out 0-group samples and non-representative samples. For the **IndExpr** we set *length>x* where x is the max size of 0-group fish (typically 5.5-6.5 cm) in order to filter out 0-group fish from the estimation based on a length cut-off.
For the process RegroupLengthDist a **LengthInterval** of *0.5* was used.

For the process BioStationAssignment we use **AssignmentMethod** *Stratum*.
In the process BioStationWeighting we use **WeightingMethod** *NASC* with **Radius** *10*, **m** *19.1* and **a** *-74*.
Similarly, in the process AcousticDensity **m** was set to *19.1* and **a** to *-74*.

Estimation of sampling variance in StoX
Confidence intervals for different estimators of population parameters were estimated by using StoX with a stratified bootstrap routine treating each transect as the primary sampling unit. In addition, a bootstrap routine for all trawl stations by strata was carried out within each run. The bootstrap routine was iterated 500 times for the estimates and comparisons in the present working document. Note that a re-estimation using 1000 replicates was done for BS3 in the appendix of the present report, and the results shown in Fig. 6 are based on this re-estimation.

Capelin biomass estimation using BEAM (2002-2015)
From 2002-2015, the capelin biomass estimation was done using BEAM, an IMR in-house software designed for fish stock biomass estimation (Totland & Godø 2001). Today, computing power sets few limits to efficient estimation of biomass and associated sampling variance for large-scale surveys, but historically this was an issue. A way to come around this which was implemented in BEAM for pelagic fish surveys at IMR, was to divide the survey area into rectangles of 1° latitude by 2 ° longitude (Toresen et al. 1998). Following the same general approach as described in the section above, an arithmetic mean NASC was estimated per rectangle based on all 1 nmi capelin acoustic output values present within a given rectangle. Length distributions for the abundance estimation were based on biological samples from trawl hauls within a given rectangle considered to be representative for the acoustic registrations of capelin in the rectangle. Since trawls hauls were typically not conducted in all rectangles, stations were in many cases allocated from neighbouring rectangles and an important part of the estimation process was the manual allocation of biological stations. When the estimation per rectangle was done, the survey area was divided in four sub-areas (north-west and north-east, south-west and south-east), and population parameter estimates were made according to age-length keys per sub-area based on data on individual capelin within the given sub-area.

The BEAM software did not accommodate estimation of sampling variance, and the capelin monitoring data were not collected according to a design allowing for easy and routinely estimation of sampling variance (for example stratified random transect based). However, Tjelmeland (2002) developed a generic uncertainty model for the capelin estimate in order to evaluate historical uncertainty in the capelin estimates. The model was based on the resampling of pooled historical acoustic and biological data onto a standardized geographical grid, and the model reflects differences in sampling effort within each grid cell. Following from this work, a fixed CV of 0.2 per age group was derived as a 'typical' CV and applied to the survey derived biomass of maturing capelin for all age groups in the stock projection model (Gjøsæter et al. 2002). The inclusion of a fixed CV derived from an uncertainty model instead of just a plain mean value, was clearly a step forward in expressing that there is inherent uncertainty associated with the survey results. However, the drawback of using a fixed CV is that it will not always reflect a realistic sampling variance which is also indicated in figs. 5-7 in Tjelmeland (2002).

Re-estimation of biomass for 2004-2015 using StoX
We re-estimated biomass and abundance of capelin for 2004-2015 using StoX. We used the same settings as described in the section above, but since these surveys were not conducted according to a strict design, some choices had to be made with regards to the re-estimation

process. The assumptions and settings used for re-estimating capelin abundance from historical data in StoX are listed below here:

Data
We used the most recent versions of biotic data with time stamp and acoustic data downloaded from the IMR-database datasetexplorer.

Stratification (StoX process DefineStrata)

1) Stratify according to allocation of effort (Similar sampling effort within a given stratum)
2) Strata borders at the position where a transect ends
3) Strata limits along transects: follow the transect, not include more area
4) In special cases where you only have a single transect (see e.g. for 2013 in the north-east): half the typical inter-transect distance included on each side of the transect.

Transects (StoX process DefineAcousticTransect)

1) Exclude transits where there are clear transits and transects (e.g. Great Bank west in 2015, fig. A1d)
2) Include all data in cases where there are no clear transits and transects
3) Tag a transect as either a straight line crossing an area, or two joint line segments with ≥90° angle.

Filter biotic data (StoX process FilterBiotic)

1) Include the same trawl stations as were used in the original BEAM estimates (but weighted by NASC as described in point 4) in the section above).
2) Only include capelin with lengths > x similar as is currently done to exclude fish with lengths <x, but in the re-estimation the same x is used as was used in the original BEAM estimate.

Results and discussion

Capelin length distribution derived from biological samples

Since capelin are sampled on three different platforms (0-group hauls, target hauls and demersal hauls), and the size distributions vary strongly between platforms (Fig. 3), the allocation and weighting of station data to provide capelin length distributions is a crucial step in the estimation. The method for allocation is looked further into in BS3 in the appendix of this report.

Comparison of estimates in BEAM and StoX

For most of the years, the estimated abundance-at-length from BEAM are within the 90% confidence bands of the StoX estimates for all length groups (Fig. 4). There are a few exceptions, but then mostly for length groups <10 cm, and then for 2014 there is discrepancy also for older age groups, but this was a very particular sampling year (see section ***Design of the survey and coverage***). The biomass estimates from BEAM are also within the 90% confidence interval of the StoX biomass estimates for all years (Fig. 5. The BEAM estimates are higher than the median StoX-estimate for 8 of 12 years (see table 2), and mean ratio between StoX estimates and BEAM estimates is ca. 0.96. The tendency of higher estimates in BEAM could be due to different assumptions of area to include (in BEAM the area estimation is based on fixed rectangles rather than strata).

Estimates of sampling variance

Sampling variance by age expressed as Coefficient of Variation (CV) for all years is shown in Figure 6. The results show that there is a strong year-to-year variability which was also shown in Tjelmeland (2002), but which is presently not incorporated in stock assessment and projection. It should be noted that these results are based on all fish included in the estimate for a given age group, and not only the maturing fish which are going into the stock projection model. Still, the results indicate that the sampling variance differs between age groups, with the highest estimates typically for 3-year-olds whereas a fixed sampling variance of 0.2 for all age groups is implemented in the projection model. There was a high correlation of sampling variance at age between age groups over the period, indicating that the acoustic sampling and not the biological sampling is the main driver of the variance. We suggest that either such annual CV-estimates from StoX for maturing capelin are used in the stock projection in the future, or that random bootstrap replicates from StoX are used directly in the projection through R-bifrost. The implementation of sampling variance is further described and discussed in BS3 in the Appendix of the current report.

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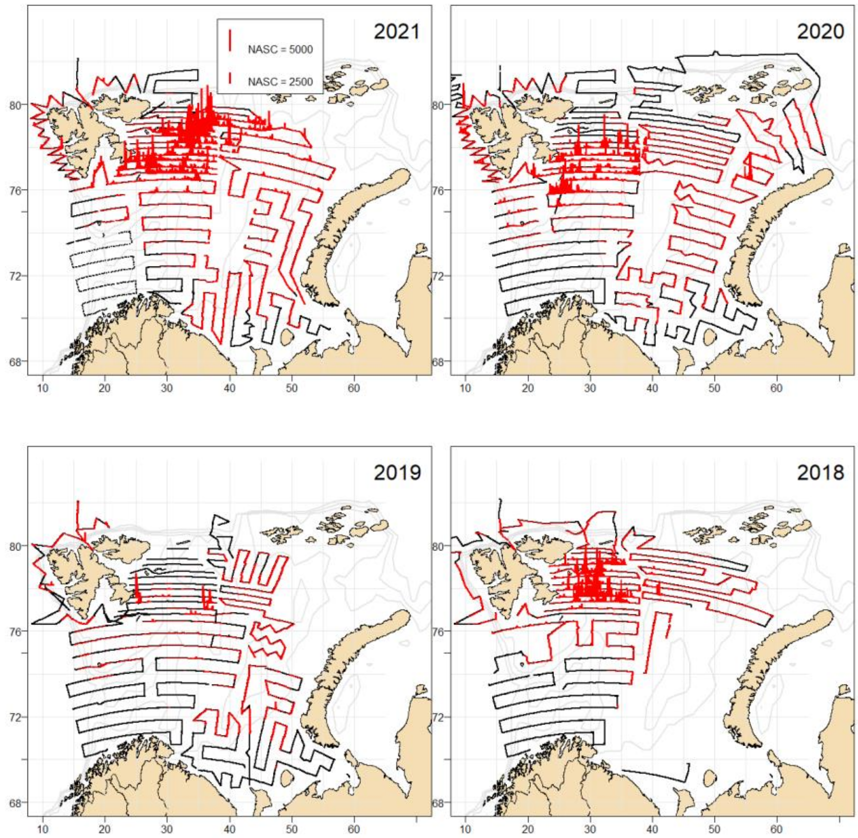
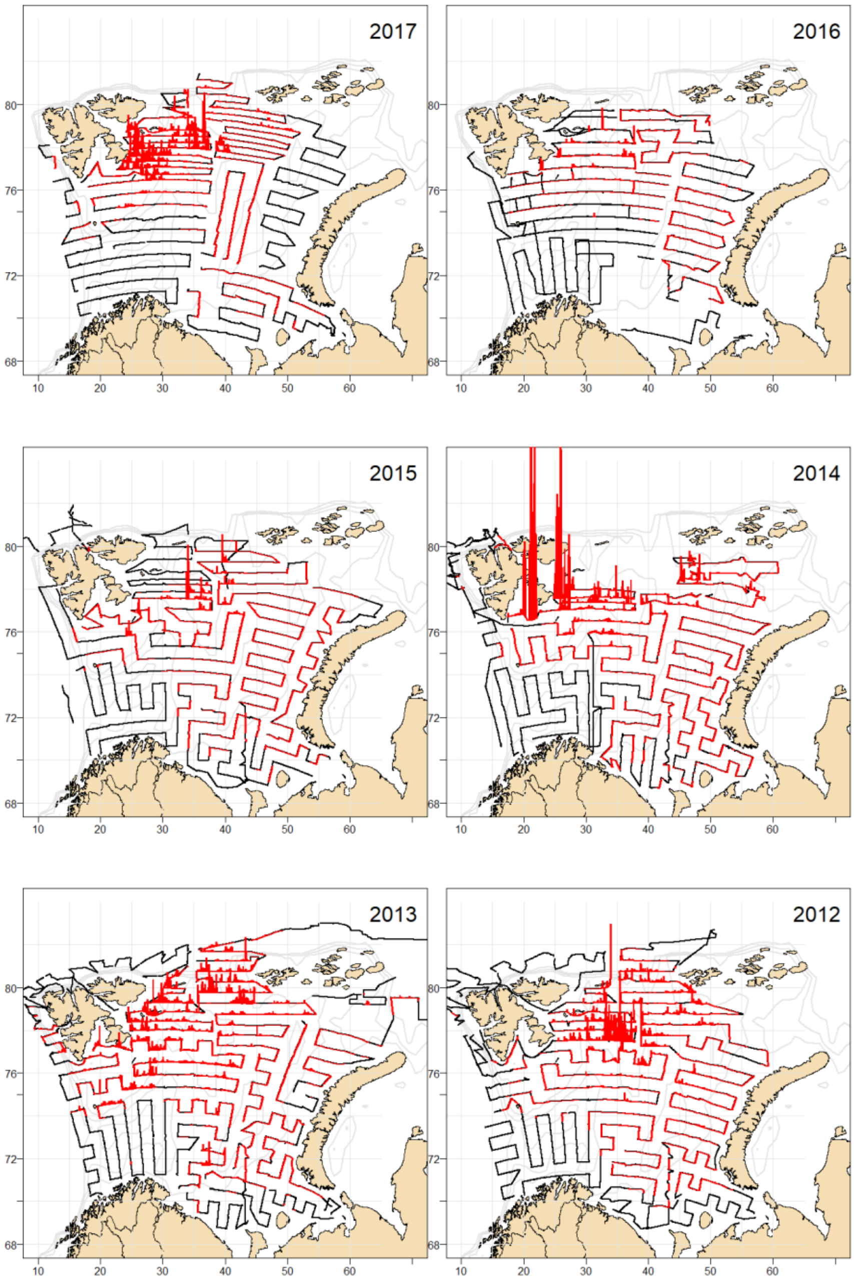
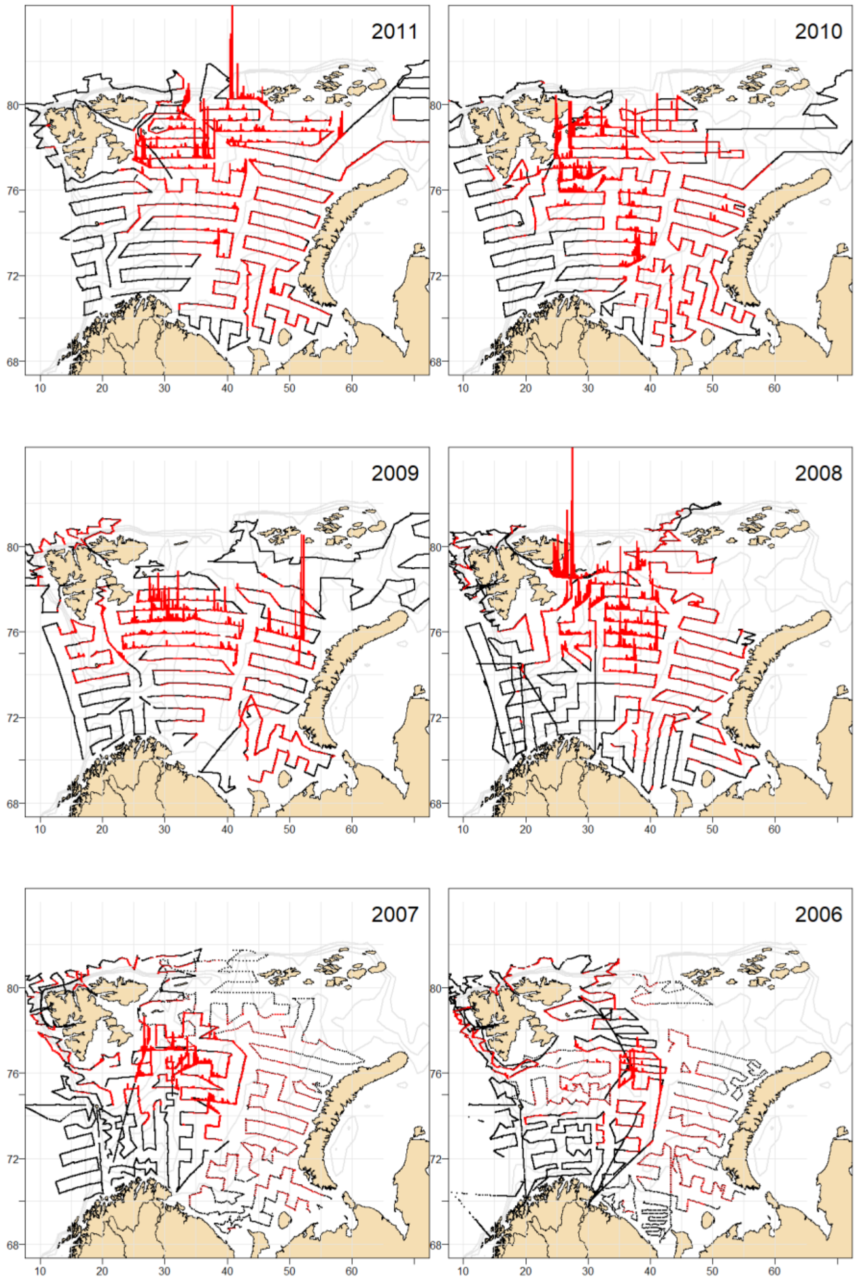
Figures and tables




2017
2016
2015
2014
2013
2012
80
76
72
68
10
20
30
40
50
60


2011
2010
2009
2008
2007
2006
80
76
72
68
10
20
30
40
50
60

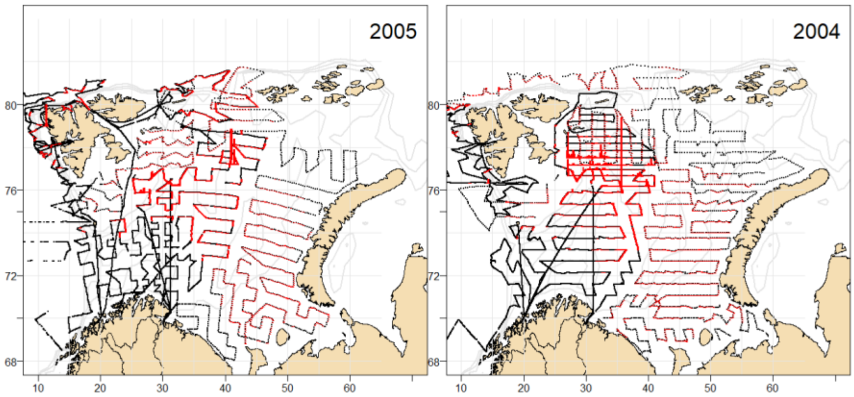


Figure 1. Acoustic recordings included in the biomass estimation of capelin from 2004-2021. The height of each bar is proportional to the measured capelin NASC (m^2/nmi^2) averaged over a given nautical mile, and the scaling is given in the legend of the 2021 figure panel. However, note that data were stored at a resolution of 5 nautical miles on Russian vessels from 2004-2007 so capelin NASC in these cases are averaged over 5 nautical miles.

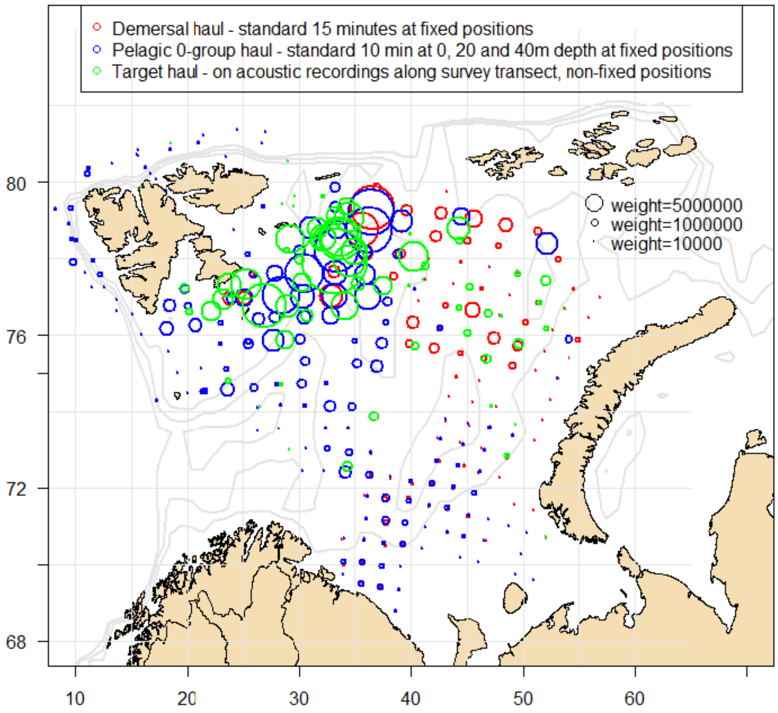
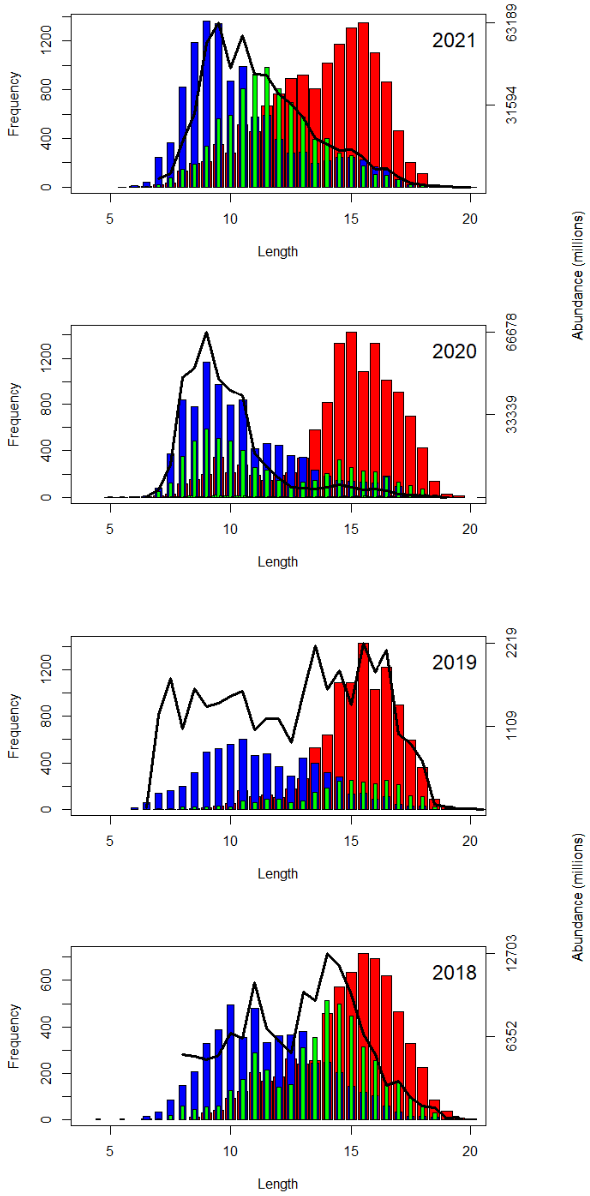
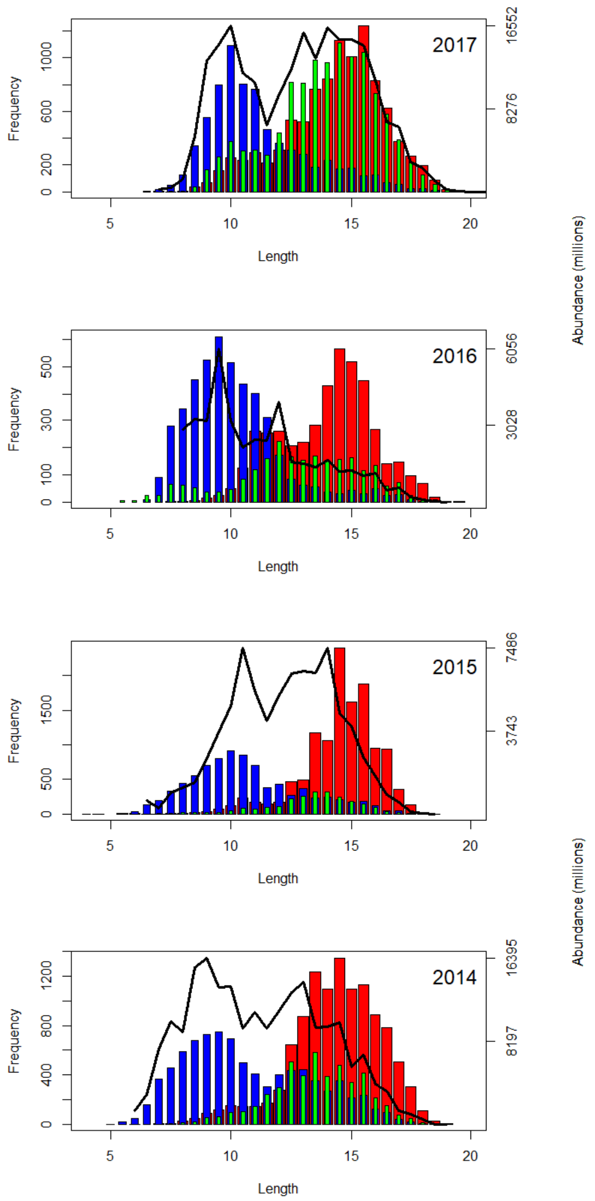


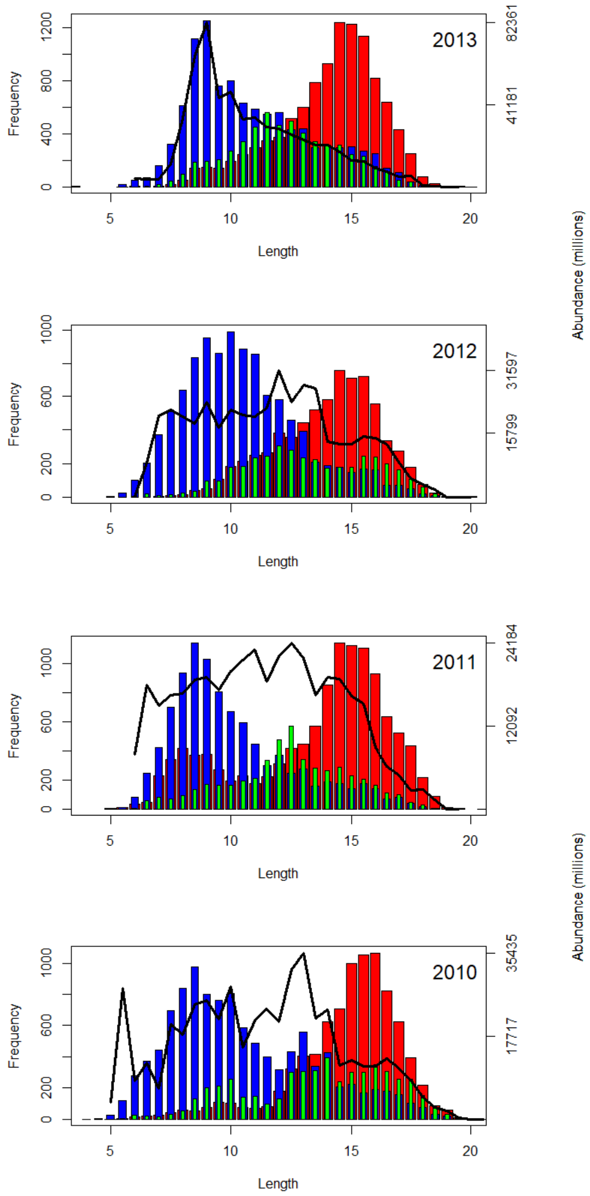
Figure 2. Overview of trawl samples included in the capelin biomass estimation in 2021. The colour of the circles refer to different types of hauls, and the size of the circles are proportional to the square root of the weighting factor (in the unit of number of individuals per square nautical mile).

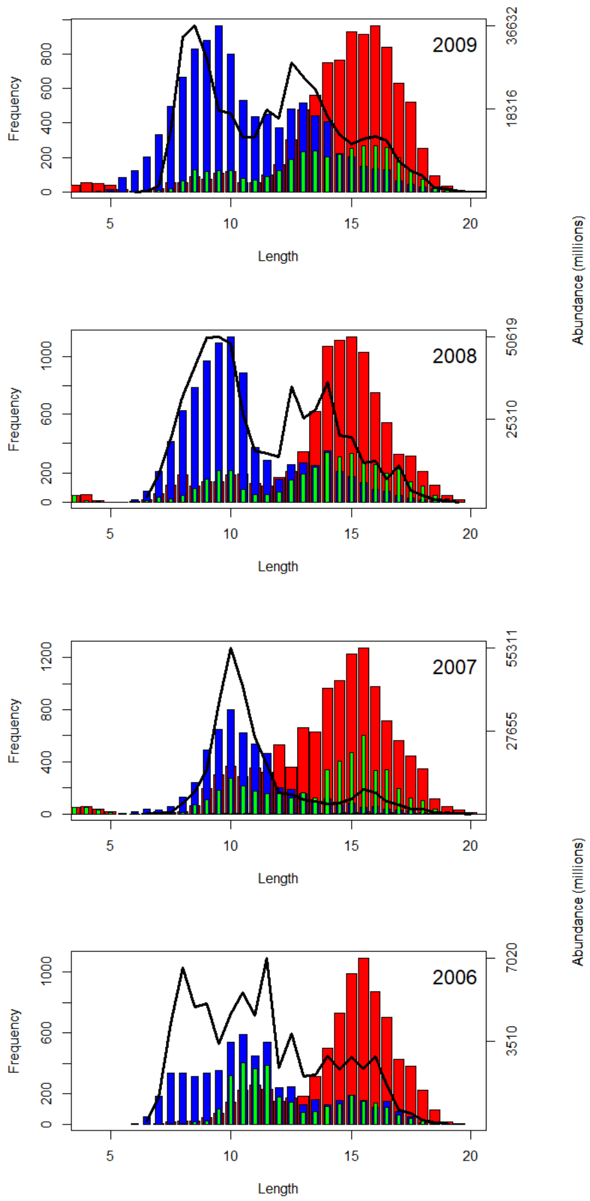


2021
2020
2019
2018
Frequency
Length
Abundance (millions)
63189
31594
66678
33339
2219
1109
12703
6352



2017
2016
2015
2014
Frequency
Length
Abundance (millions)
16552
8276
6056
3028
7486
3743
16395
8197


2013
Frequency
0
400
800
1200
41181
82361
5
10
15
20
Length
Abundance (millions)
2012
Frequency
0
200
600
1000
15799
31597
5
10
15
20
Length
2011
Frequency
0
200
600
1000
12092
24184
5
10
15
20
Length
Abundance (millions)
2010
Frequency
0
200
600
1000
17717
35435
5
10
15
20
Length


2009
Frequency
0
200
400
600
800
18316
36632
5
10
15
20
Length
2008
Frequency
0
200
600
1000
25310
50619
5
10
15
20
Length
2007
Frequency
0
400
800
1200
27655
55311
5
10
15
20
Length
2006
Frequency
0
200
600
1000
3510
7020
5
10
15
20
Length
Abundance (millions)
Abundance (millions)

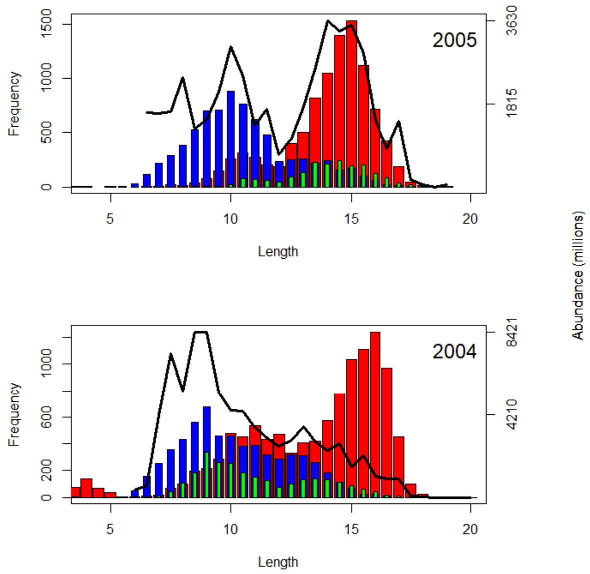
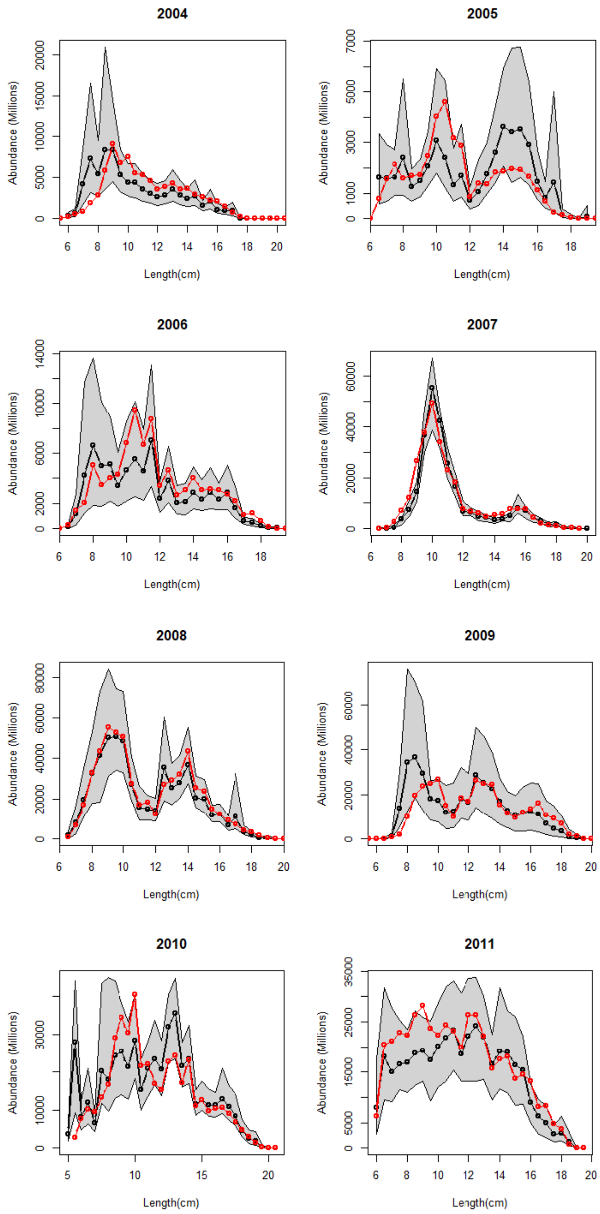


Figure 3. Capelin length distribution for 2004-2021 from all trawl hauls with red bars indicating demersal hauls (fixed positions), blue bars 0-group hauls and green bars target hauls. The black line indicates estimated length distribution from StoX (median run) with abundance given on the right-hand axis.


2004
2005
2006
2007
2008
2009
2010
2011
Abundance (Millions)
Length(cm)

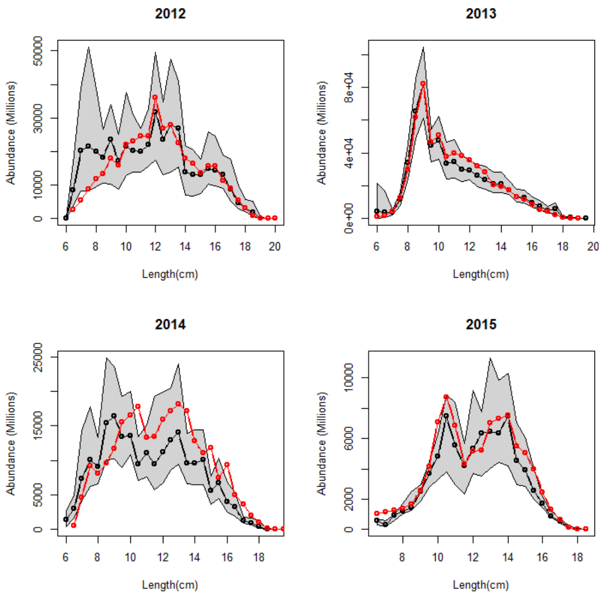


Figure 4. Estimated median (black line) with 5-95% confidence interval (greyed area) length distribution of capelin from biomass estimation software StoX, and estimated length distribution from estimation software BEAM denoted as red line.

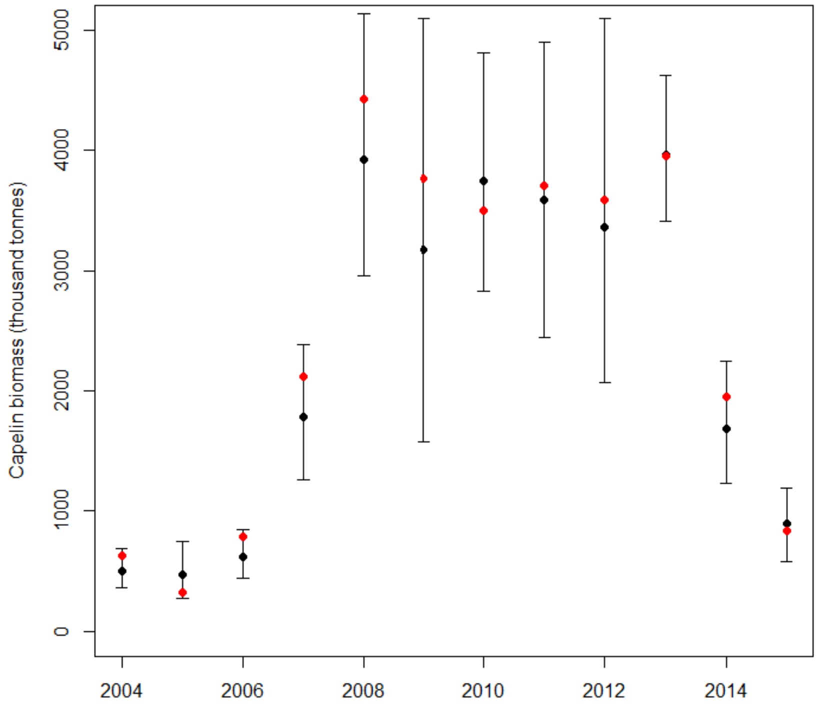


Figure 5. Comparison of biomass estimates from StoX and BEAM where estimates from StoX are marked with black dots (median bootstrap run) and black whiskers marking 5% and 95% limits, while estimates from BEAM (only mean values available) are marked with red dots.

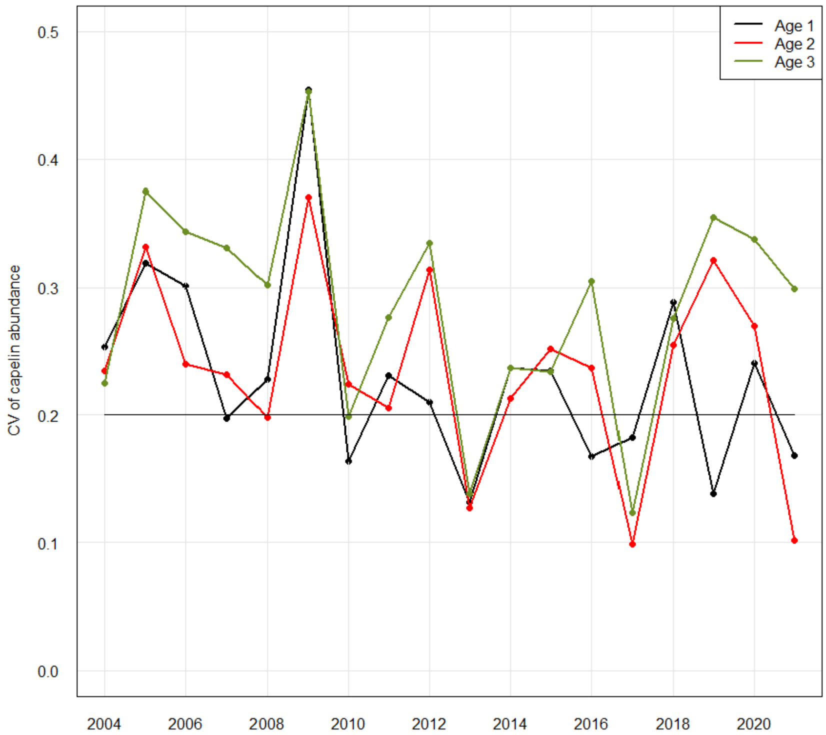


Figure 6. Estimated sampling variance expressed as CV of abundance for capelin based on re-estimation using StoX. The black horizontal line marks a CV of 0.2 which is presently used as a fixed value for maturing capelin of all age groups in the stock projection. The estimates are based on 1000 bootstrap replicates.

Table 1. Overview of surveys and vessels going into the capelin biomass estimation from 2004-2021 including Sea2Data cruise number, name of vessels, and start and end dates.

Year	Cruise number	Vessel	Start date	Stop date
2004	0088_2004	Fritjof Nansen	2004-08-17	2004-09-28
	0118_2004	Smolensk	2004-08-07	2004-09-28
	2004210	Johan Hjort	2004-08-01	2004-10-03
	2004702	Jan Mayen	2004-08-07	2004-08-21
2005	0092_2005	Smolensk	2005-08-12	2005-09-19
	0093_2005	Fritjof Nansen	2005-06-09	2005-12-09
	2005111	GO Sars	2005-08-06	2005-09-26
	2005209	Johan Hjort	2005-08-02	2005-09-07
	2005702	Jan Mayen	2005-08-04	2005-08-20
	2005703	Jan Mayen	2005-09-13	2005-09-24

Year	Cruise number	Vessel	Start date	Stop date
2006	0094_2006	Fritjof Nansen	2006-08-15	2006-09-25
	0095_2006	Smolensk	2006-08-19	2006-09-21
	2006113	GO Sars	2006-08-18	2006-09-26
	2006211	Johan Hjort	2006-08-14	2006-09-18
	2006702	Jan Mayen	2006-08-07	2006-08-16
	2006704	Jan Mayen	2006-09-12	2006-09-27
2007	0096_2007	Smolensk	2007-08-23	2007-09-20
	0097_2007	Vilnyus	2007-08-14	2007-09-15
	2007110	GO Sars	2007-08-15	2007-09-28
	2007210	Johan Hjort	2007-08-02	2007-09-23
	2007702	Jan Mayen	2007-09-10	2007-09-26
2008	0100_2008	Vilnyus	2008-08-09	2008-09-19
	2008106	GO Sars	2008-08-19	2008-09-17
	2008208	Johan Hjort	2008-09-02	2008-09-15
	2008703	Jan Mayen	2008-09-08	2008-10-03
	2008822	Atlantic star	2008-08-02	2008-08-09
2009	0105_2009	Vilnyus	2009-08-12	2009-09-26
	2009109	GO Sars	2009-08-20	2009-09-04
	2009208	Johan Hjort	2009-08-24	2009-10-02
	2009702	Jan Mayen	2009-09-10	2009-09-25
2010	0106_2010	Vilnyus	2010-08-14	2010-09-19
	0107_2010	Fritjof Nansen	2010-08-14	2010-08-22
	2010111	GO Sars	2010-08-24	2010-09-12
	2010210	Johan Hjort	2010-08-29	2010-09-23
	2010703	Jan Mayen	2010-08-26	2010-09-12
2011	0109_2011	Vilnyus	2011-08-14	2011-09-24
	2011213	Johan Hjort	2011-08-31	2011-09-29
	2011717	Helmer Hanssen	2011-08-09	2011-08-20
	2011830	Christina E	2011-08-27	2011-09-17
2012	0110_2012	Vilnyus	2012-08-12	2012-09-24
	2012111	GO Sars	2012-08-18	2012-09-11
	2012209	Johan Hjort	2012-08-23	2012-09-23
	2012845	Helmer Hanssen	2012-08-22	2012-09-03
2013	0112_2013	Vilnyus	2013-08-12	2013-10-21
	2013111	GO Sars	2013-08-24	2013-09-17
	2013208	Johan Hjort	2013-08-21	2013-09-19
	2013843	Helmer Hanssen	2013-08-19	2013-08-30
2014	0116_2014	Vilnyus	2014-08-15	2014-09-28
	2014116	GO Sars	2014-09-07	2014-09-21
	2014212	Johan Hjort	2014-08-13	2014-09-20
	2014806	Helmer Hanssen	2014-08-20	2014-09-04
2015	0117_2015	Vilnyus	2015-08-22	2015-10-06
	2015114	GO Sars	2015-09-12	2015-09-25
	2015210	Johan Hjort	2015-08-14	2015-09-24
	2015843	Helmer Hanssen	2015-08-20	2015-08-30
2016	0142_2016	Fritjof Nansen	2016-08-11	2016-09-21
	2016209	Johan Hjort	2016-08-22	2016-09-29
	2016842	Eros	2016-08-22	2016-09-17
2017	0143_2017	Vilnyus	2017-08-27	2017-10-13
	2017113	GO Sars	2017-09-03	2017-09-22
	2017209	Johan Hjort	2017-08-23	2017-09-29
2018	0145_2018	Vilnyus	2018-08-03	2018-09-29
	2018110	GO Sars	2018-09-08	2018-09-28
	2018209	Johan Hjort	2018-08-23	2018-09-29
	2018838	Helmer Hanssen	2018-09-15	2018-09-29
2019	0147_2019	Vilnyus	2019-08-16	2019-09-29
	2019113	GO Sars	2019-08-14	2019-09-08
	2019209	Johan Hjort	2019-08-21	2019-09-26
	2019813	Helmer Hanssen	2019-09-22	2019-10-02
2020	0151_2020	Vilnyus	2020-09-29	2020-11-10
	0152_2020	Atlantniro	2020-09-17	2020-10-12
	2020111	GO Sars	2020-08-14	2020-09-06

Year	Cruise number	Vessel	Start date	Stop date
	2020209	Johan Hjort	2020-08-22	2020-09-27
	2020706	Kronprins Haakon	2020-09-17	2020-10-08
2021	0154_2021	Vilnyus	2021-08-21	2021-09-09
	2021108	GO Sars	2021-09-13	2021-09-27
	2021209	Johan Hjort	2021-08-12	2021-09-26
	2021848	Helmer Hanssen	2021-08-19	2021-09-25

Table 2. Comparison between StoX and BEAM estimates with deviance in tons (second column) and ratio (third column) between estimates done in StoX and BEAM.

Year	Deviance StoX - BEAM (tons)	Ratio StoX/BEAM
2004	-122	0.81
2005	148	1.46
2006	-165	0.79
2007	-335	0.84
2008	-504	0.89
2009	-585	0.84
2010	248	1.07
2011	-114	0.97
2012	-224	0.94
2013	4	1.00
2014	-269	0.86
2015	53	1.06

Appendix

Fig. A1a) Overview of StoX estimation projects for 2021 (left) and 2020 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

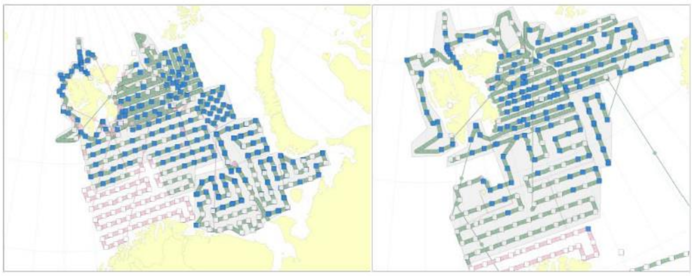


Fig. A1b) Overview of StoX estimation projects for 2019 (left) and 2018 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

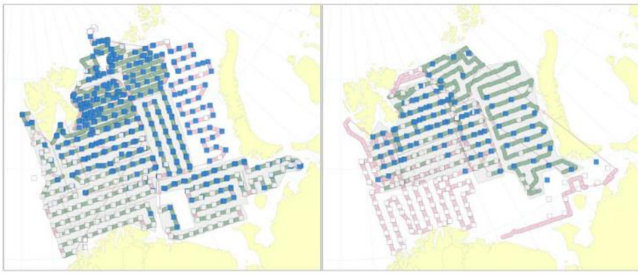


Fig. A1c) Overview of StoX estimation projects for 2017 (left) and 2016 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

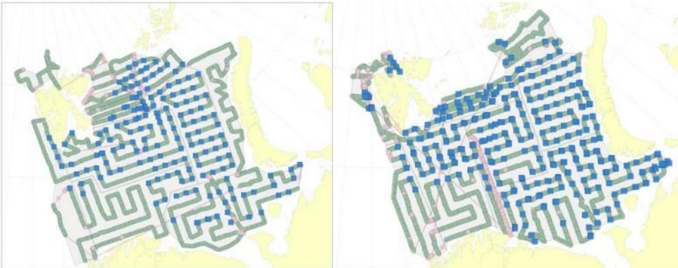


Fig. A1d) Overview of StoX estimation projects for 2015 (left) and 2014 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

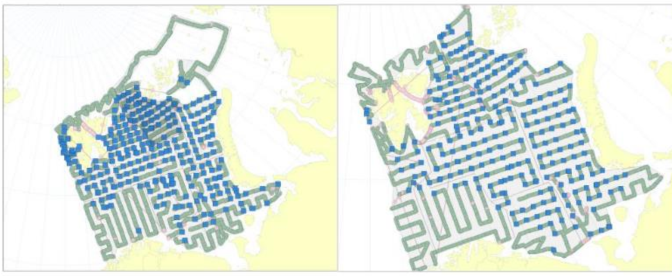


Fig. A1e) Overview of StoX estimation projects for 2013 (left) and 2012 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

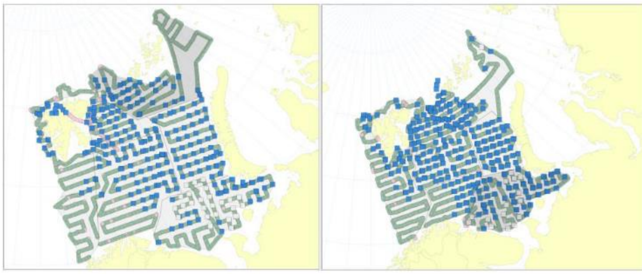


Fig. A1f) Overview of StoX estimation projects for 2011 (left) and 2010 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

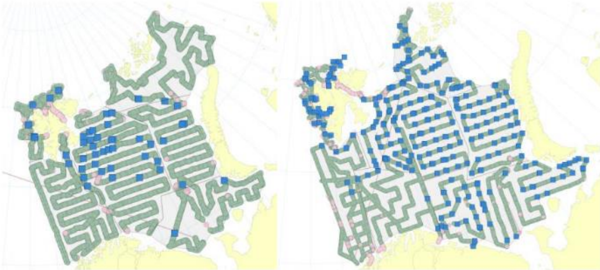


Fig. A1g) Overview of StoX estimation projects for 2009 (left) and 2008 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

Fig. A1h) Overview of StoX estimation projects for 2007 (left) and 2006 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

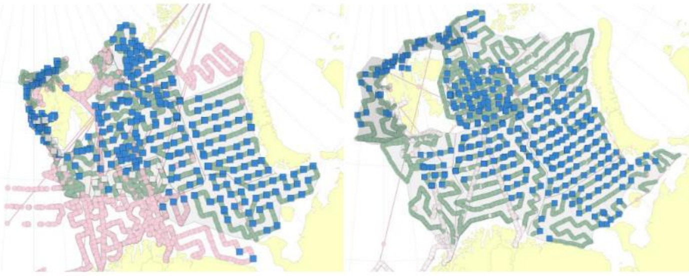


Fig. A1i) Overview of StoX estimation projects for 2005 (left) and 2004 (right) with tagged acoustic data marked in green and non-tagged in pink, stations with capelin sampled in blue and stations without capelin marked in white. The strata are marked in gray.

Fig. 2004

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-6.5	0.372					0.372	0.372	1.000
6.5-7	0.612					0.612	0.612	1.000
7-7.5	4.588					4.588	4.588	1.000
7.5-8	8.510					8.510	13.865	1.630
8-8.5	5.933					5.933	11.015	1.860
8.5-9	10.347					10.347	23.027	2.230
9-9.5	9.193	0.059				9.253	24.750	2.670
9.5-10	5.626	0.055				5.681	18.217	3.210
10-10.5	4.640	0.014				4.654	18.088	3.890
10.5-11	4.466	0.016				4.482	20.644	4.610
11-11.5	3.540	0.148				3.688	20.341	5.520
11.5-12	2.449	0.666	0.011			3.126	20.234	6.470
12-12.5	1.692	0.972				2.664	20.537	7.710
12.5-13	1.371	1.720	0.006			3.097	26.753	8.640
13-13.5	0.665	3.078	0.003			3.746	37.572	10.030
13.5-14	0.087	2.796	0.055			2.938	33.940	11.550
14-14.5	0.073	2.199	0.211			2.482	32.461	13.080
14.5-15	0.037	2.455	0.401			2.893	44.390	15.340
15-15.5	0.049	0.937	0.551	0.033		1.570	27.404	17.450
15.5-16	0.180	1.075	0.820	0.112		2.187	42.776	19.560
16-16.5	0.008	0.283	0.649	0.162	0.009	1.111	22.622	20.360
16.5-17		0.059	0.750	0.127		0.936	22.847	24.420
17-17.5		0.005	0.762	0.164	0.103	1.035	28.805	27.830
17.5-18		0.000	0.052	0.008		0.060	1.758	29.460
18-18.5		0.005	0.009	0.003		0.016	0.547	33.460
18.5-19			0.001			0.001	0.039	29.000
19-19.5					0.012	0.012		
19.5-20					0.004	0.004		
TSN(10^9)	64.438	16.542	4.281	0.609	0.128	85.997		
TSB(10^3 t)	209.881	203.078	89.218	13.161	2.865		518.202	
Mean length (cm)	9.120	13.560	15.770	16.260	16.920			
Mean weight (g)	3.260	12.280	20.840	21.620	25.530			6.030
MSN 10^9	0.347	7.019	4.206	0.609	0.128			
MSB 10^3 t	6.056	111.315	89.163	14.057	3.053		223.649	

2005

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	1.815					1.815	1.815	1.000
7-7.5	1.733					1.733	1.733	1.000
7.5-8	1.738					1.738	3.477	2.000
8-8.5	2.506					2.506	4.699	1.870
8.5-9	1.273					1.273	3.814	3.000
9-9.5	1.463					1.463	4.436	3.030
9.5-10	2.013					2.013	7.542	3.750
10-10.5	3.143	0.009				3.152	13.462	4.270
10.5-11	2.694	0.006				2.699	13.430	4.980
11-11.5	1.410	0.002				1.412	8.200	5.810
11.5-12	1.472	0.353				1.825	11.848	6.490
12-12.5	0.457	0.194				0.652	5.620	8.620
12.5-13	0.174	0.965	0.007			1.146	10.691	9.330
13-13.5	0.111	1.595	0.026			1.732	18.162	10.480
13.5-14	0.004	2.743	0.019			2.766	33.397	12.070
14-14.5		3.570	0.144	0.015		3.729	50.790	13.620
14.5-15		3.310	0.363	0.096		3.770	57.549	15.270
15-15.5		3.112	0.689	0.050		3.851	65.987	17.130
15.5-16		2.366	0.712	0.061		3.139	60.002	19.120
16-16.5		1.075	0.430	0.036		1.541	34.007	22.070
16.5-17		0.554	0.287	0.033	0.003	0.878	21.735	24.770
17-17.5		0.999	0.771	0.028	0.046	1.846	52.438	28.410
17.5-18		0.051	0.104	0.019	0.001	0.174	5.080	29.130
18-18.5		0.009	0.052			0.061	2.009	32.850
18.5-19					0.001	0.001		
19-19.5					0.187	0.187		
TSN(10^9)	22.006	20.914	3.605	0.339	0.238	47.101		
TSB(10^3 t)	0.000	329.574	75.968	6.101	0.000		491.923	
Mean length (cm)	9.480	14.450	15.760	15.470	16.980			
Mean weight (g)	4.010	15.760	21.070	18.010	18.340			10.490
MSN 10^9	0.000	15.047	3.552	0.339	0.238			
MSB 10^3 t	0.000	265.349	76.168	6.678	1.409		349.596	

2006

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	0.146					0.146		
7-7.5	1.220					1.220		
7.5-8	4.541					4.541	9.082	2.000
8-8.5	6.937					6.937	13.871	2.000
8.5-9	5.159					5.159	10.533	2.040
9-9.5	5.164					5.164	15.810	3.060
9.5-10	3.471					3.471	12.060	3.470
10-10.5	4.751	0.011				4.762	20.553	4.320
10.5-11	5.672	0.001				5.673	28.825	5.080
11-11.5	4.136	0.588				4.724	27.688	5.860
11.5-12	7.500	0.069	0.013			7.583	50.330	6.640
12-12.5	2.317	0.073				2.389	18.343	7.680
12.5-13	3.285	0.876				4.161	35.855	8.620
13-13.5	0.880	1.171	0.084			2.135	22.073	10.340
13.5-14	0.214	1.900	0.113			2.227	26.568	11.930
14-14.5	0.038	2.621	0.414			3.072	42.577	13.860
14.5-15		1.987	0.488			2.476	40.006	16.160
15-15.5		2.570	0.414	0.012		2.996	52.565	17.550
15.5-16		1.715	0.766			2.481	50.092	20.190
16-16.5		2.034	1.050	0.008		3.092	71.547	23.140
16.5-17		0.862	0.834	0.073	0.019	1.788	45.396	25.390
17-17.5		0.312	0.292	0.009		0.613	17.440	28.450
17.5-18		0.140	0.336	0.014		0.490	15.668	31.940
18-18.5		0.034	0.148	0.010		0.192	6.734	35.150
18.5-19		0.006	0.065		0.004	0.074	2.825	37.970
19-19.5		0.050	0.005			0.055	2.572	46.420
TSN(10^9)	54.067	17.020	5.023	0.125	0.023	77.623		
TSB(10^3 t)	241.695	276.428	116.847	3.441	0.601		639.011	
Mean length (cm)	9.930	14.510	15.750	16.590	16.810			
Mean weight (g)	4.470	16.240	23.260	27.490	26.460			8.380
MSN 10^9	0.038	12.331	4.814	0.125	0.023			
MSB 10^3 t	0.523	234.193	108.833	3.278	0.621		347.422	

2007

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	0.244					0.244	0.244	1.000
7-7.5	0.370					0.370	0.390	1.050
7.5-8	0.901					0.901	1.604	1.780
8-8.5	3.373					3.373	7.964	2.360
8.5-9	7.556					7.556	20.111	2.660
9-9.5	15.340					15.340	45.767	2.980
9.5-10	36.054					36.054	120.431	3.340
10-10.5	51.031					51.031	200.361	3.930
10.5-11	35.270	0.820				36.090	163.420	4.530
11-11.5	22.524	2.152				24.676	125.502	5.090
11.5-12	14.111	1.600				15.711	95.177	6.060
12-12.5	4.760	2.689	0.011			7.461	53.275	7.140
12.5-13	3.202	3.150				6.352	52.503	8.270
13-13.5	1.036	3.937				4.972	50.258	10.110
13.5-14	0.484	3.382				3.866	45.745	11.830
14-14.5	0.296	2.580	0.119			2.995	40.468	13.510
14.5-15	0.407	2.962	0.057			3.427	52.751	15.390
15-15.5	0.053	4.919	0.037			5.009	86.504	17.270
15.5-16	0.016	8.909	0.387			9.312	180.245	19.360
16-16.5	0.013	5.797	0.478			6.288	136.111	21.650
16.5-17	0.004	4.034	0.648	0.006		4.692	114.685	24.440
17-17.5		1.612	1.320	0.074		3.006	83.895	27.910
17.5-18		1.082	0.445	0.026		1.554	48.020	30.900
18-18.5		0.155	1.300	0.051		1.506	51.271	34.040
18.5-19		0.099	0.361	0.018		0.479	18.081	37.770
19-19.5		0.173	0.155			0.328	13.410	40.900
19.5-20			0.077			0.077	3.457	45.000
20-20.5				0.000		0.000		
TSN(10^9)	197.044	50.051	5.396	0.175		252.667		
TSB(10^3 t)	843.387	806.960	156.143	5.158			1,811.647	
Mean length (cm)	10.160	14.460	17.100	17.540				
Mean weight (g)	4.280	16.120	28.930	29.420				7.170
MSN 10^9	0.789	32.322	5.385	0.175	0.000			
MSB 10^3 t	11.865	656.486	155.109		0.000		828.897	

2008

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	1.768					1.768	1.912	1.080
7-7.5	8.120					8.120	9.191	1.130
7.5-8	20.616					20.616	35.229	1.710
8-8.5	32.069					32.069	61.695	1.920
8.5-9	40.021					40.021	91.222	2.280
9-9.5	47.333					47.333	133.050	2.810
9.5-10	46.728	0.220				46.948	143.978	3.070
10-10.5	46.735					46.735	172.891	3.700
10.5-11	24.798					24.798	107.086	4.320
11-11.5	13.470	1.041				14.511	73.184	5.040
11.5-12	8.262	5.332	0.013			13.608	83.019	6.100
12-12.5	1.652	10.985				12.637	91.208	7.220
12.5-13	0.553	29.719				30.272	247.861	8.190
13-13.5	0.176	23.760				23.937	226.058	9.440
13.5-14	0.005	27.367				27.372	297.647	10.870
14-14.5	0.217	35.202	0.336			35.755	440.733	12.330
14.5-15		19.692	0.393			20.085	283.281	14.100
15-15.5	0.000	17.923	0.899			18.822	300.601	15.970
15.5-16		9.772	1.764			11.536	207.610	18.000
16-16.5		8.382	3.346			11.728	240.746	20.530
16.5-17		3.519	3.318	0.129		6.966	158.600	22.770
17-17.5		4.094	9.066	0.129		13.289	336.788	25.340
17.5-18		0.886	2.797			3.683	106.468	28.910
18-18.5		0.203	1.823	0.077		2.103	67.939	32.310
18.5-19		0.058	0.367	0.114		0.538	19.202	35.660
19-19.5		0.086	0.456	0.035		0.578	23.224	40.210
19.5-20				0.017		0.017		
TSN(10^9)	292.524	198.241	24.576	0.502		515.844		
TSB(10^3 t)	893.318	2,459.593	593.967	13.547			3,960.425	
Mean length (cm)	9.220	13.820	16.720	17.520				
Mean weight (g)	3.070	12.410	24.170	27.940				7.680
MSN 10^9	0.217	99.816	24.563	0.502	0.000			
MSB 10^3 t	2.679	1,567.458	600.913		0.000		2,185.193	

2009

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-6.5	0.000					0.000	0.000	1.000
6.5-7	1.078					1.078	1.078	1.000
7-7.5	3.094					3.094	3.363	1.090
7.5-8	18.413					18.413	28.630	1.550
8-8.5	38.683	2.263				40.945	81.244	1.980
8.5-9	39.040					39.040	89.287	2.290
9-9.5	31.612					31.612	87.140	2.760
9.5-10	14.976					14.976	49.854	3.330
10-10.5	13.805	0.551				14.356	56.776	3.950
10.5-11	9.002	1.330				10.332	47.858	4.630
11-11.5	6.676	4.724				11.401	62.142	5.450
11.5-12	1.824	14.825				16.649	108.177	6.500
12-12.5	0.051	14.283				14.333	103.953	7.250
12.5-13	0.280	25.265				25.544	215.604	8.440
13-13.5	0.003	24.380				24.383	237.112	9.720
13.5-14	0.067	20.319	0.201			20.587	223.061	10.830
14-14.5	0.044	13.702	1.169			14.915	184.510	12.370
14.5-15		10.496	1.278			11.774	167.277	14.210
15-15.5		6.070	4.293			10.362	171.697	16.570
15.5-16		4.036	7.670			11.706	224.722	19.200
16-16.5		3.449	9.162			12.611	267.603	21.220
16.5-17		1.152	9.511	0.050		10.714	246.377	23.000
17-17.5		2.322	6.721	0.011		9.054	247.185	27.300
17.5-18		2.354	4.141			6.495	205.167	31.590
18-18.5		0.496	3.928			4.423	147.156	33.270
18.5-19		0.242	1.270			1.512	56.582	37.430
19-19.5			0.733			0.733	29.495	40.240
19.5-20			0.327			0.327	14.836	45.360
TSN(10^9)	178.647	152.257	50.405	0.061		381.369		
TSB(10^3 t)	484.049	1,680.463	1,191.930	1.445			3,357.888	
Mean length (cm)	8.770	13.160	16.380	16.590				
Mean weight (g)	2.710	11.040	23.650	23.700				8.800
MSN 10^9	0.044	44.317	50.204	0.061	0.000			
MSB 10^3 t	0.544	759.651	1,201.058	1.448	0.000		1,962.607	

2010

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
5-5.5						0.004	0.003	0.900
5.5-6	3.420					3.420	3.406	1.000
6-6.5	4.836					4.836	4.903	1.010
6.5-7	9.781					9.781	9.896	1.010
7-7.5	6.720					6.720	6.976	1.040
7.5-8	20.314					20.314	33.628	1.660
8-8.5	24.993					24.993	48.856	1.950
8.5-9	32.942					32.942	71.637	2.170
9-9.5	33.437	0.218				33.655	89.966	2.670
9.5-10	25.166					25.166	83.908	3.330
10-10.5	28.826	0.084				28.910	110.439	3.820
10.5-11	14.407	0.477				14.884	68.441	4.600
11-11.5	18.224	1.646				19.870	104.971	5.280
11.5-12	11.123	8.026				19.149	117.105	6.120
12-12.5	4.734	13.698				18.431	128.991	7.000
12.5-13	2.881	22.659	0.171			25.712	203.311	7.910
13-13.5	0.761	28.980	0.898			30.640	280.099	9.140
13.5-14	0.586	17.818	1.160			19.564	203.105	10.380
14-14.5	0.006	20.060	1.774			21.840	255.385	11.690
14.5-15		8.320	2.968			11.289	156.783	13.890
15-15.5		4.952	6.611	0.014		11.577	186.250	16.090
15.5-16		3.854	7.948	0.011		11.813	215.815	18.270
16-16.5		1.730	9.581	0.161		11.473	244.269	21.290
16.5-17		2.165	9.484	0.500		12.149	289.581	23.840
17-17.5		0.562	9.282	0.442		10.287	280.501	27.270
17.5-18		0.158	8.098	0.313		8.569	264.634	30.880
18-18.5		0.147	4.245	0.098		4.490	151.821	33.810
18.5-19		0.050	2.400	0.098		2.548	94.933	37.250
19-19.5		0.045	1.770	0.094		1.909	75.578	39.580
19.5-20			0.281			0.281	12.378	44.060
20-20.5			0.042			0.042	1.958	47.000
20.5-21				0.000		0.000		
TSN(10^9)	243.162	135.649	66.713	1.733		447.257		
TSB(10^3 t)	762.443	1,392.135	1,596.827	48.123			3,799.528	
Mean length (cm)	9.120	13.260	16.340	17.090				
Mean weight (g)	3.160	10.260	23.940	27.770				8.500
MSN 10^9	0.006	42.044	64.484	1.733	0.000			
MSB 10^3 t	0.074	617.444	1,564.128		0.000		2,229.887	

2011

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-6.5	8.518					8.518	8.518	1.000
6.5-7	21.352					21.352	21.365	1.000
7-7.5	19.612					19.612	19.683	1.000
7.5-8	21.066					21.066	29.038	1.380
8-8.5	20.852	0.352				21.204	39.368	1.860
8.5-9	23.849	0.214				24.063	54.907	2.280
9-9.5	22.207	0.817				23.023	63.118	2.740
9.5-10	17.489	1.017				18.506	62.348	3.370
10-10.5	17.702	2.453				20.154	81.139	4.030
10.5-11	15.286	7.395				22.681	105.150	4.640
11-11.5	7.430	13.948				21.378	117.365	5.490
11.5-12	1.788	18.329				20.116	130.755	6.500
12-12.5	0.501	22.541	0.048			23.090	178.152	7.720
12.5-13	0.006	24.240	0.368			24.614	215.810	8.770
13-13.5	0.004	22.207	0.181			22.392	231.588	10.340
13.5-14	0.039	15.703	2.020			17.762	200.009	11.260
14-14.5		19.570	3.622			23.193	315.250	13.590
14.5-15		10.870	10.090			20.960	334.008	15.940
15-15.5		8.840	7.617	0.437		16.895	305.437	18.080
15.5-16		3.148	11.952	1.736		16.835	336.728	20.000
16-16.5		1.322	8.064	0.573		9.960	225.256	22.620
16.5-17		0.421	6.115	0.508		7.045	175.865	24.960
17-17.5		0.231	4.687	0.589		5.507	152.871	27.760
17.5-18			2.480	0.536		3.016	92.258	30.590
18-18.5			1.107	2.037		3.144	110.888	35.270
18.5-19			0.525	0.798		1.323	45.907	34.690
19-19.5				0.017		0.017	0.622	37.000
19.5-20				0.023		0.023	0.882	39.000
TSN(10^9)	197.701	173.617	58.878	7.254		437.450		
TSB(10^3 t)	489.904	1,740.149	1,221.219	203.012			3,654.285	
Mean length (cm)	8.430	12.710	15.520	16.900				
Mean weight (g)	2.480	10.020	20.740	27.970				8.350
MSN 10^9	0.000	44.403	56.261	7.254	0.000			
MSB 10^3 t	0.000	708.844	1,185.121	202.058	0.000		2,095.973	

2012

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-6.5	0.172					0.172		
6.5-7	6.240					6.240	6.332	1.010
7-7.5	17.073					17.073	19.091	1.120
7.5-8	15.754					15.754	22.859	1.450
8-8.5	16.789					16.789	33.650	2.000
8.5-9	16.064	0.157				16.221	38.441	2.370
9-9.5	20.745					20.745	62.076	2.990
9.5-10	15.684	0.209				15.893	52.917	3.330
10-10.5	20.041	1.090				21.132	82.298	3.890
10.5-11	16.705	2.935				19.640	91.170	4.640
11-11.5	13.467	4.710	0.271			18.447	98.702	5.350
11.5-12	6.322	14.986				21.307	133.673	6.270
12-12.5	7.760	21.316	0.161			29.237	205.610	7.030
12.5-13	1.147	18.663	0.920			20.730	166.336	8.020
13-13.5	0.308	21.999	2.476			24.783	225.016	9.080
13.5-14	0.075	18.184	6.187			24.445	254.198	10.400
14-14.5	0.095	6.573	5.076			11.744	138.915	11.830
14.5-15	0.071	4.160	7.407			11.638	159.362	13.690
15-15.5	0.045	2.056	9.040	0.006		11.147	176.598	15.840
15.5-16	0.015	2.036	13.293	0.656		16.001	287.863	17.990
16-16.5	0.008	0.931	13.425	0.411		14.775	303.395	20.530
16.5-17		0.267	12.250	0.045		12.562	295.333	23.510
17-17.5		0.201	8.559	0.636		9.397	247.241	26.310
17.5-18		0.080	4.840	0.417		5.336	155.011	29.050
18-18.5			6.122	0.429		6.551	219.857	33.560
18.5-19			2.177	0.182		2.359	83.394	35.350
19-19.5			0.051			0.051	1.794	35.500
19.5-20				0.000		0.000		
20-20.5			0.053			0.053	2.163	41.000
TSN(10^9)	174.579	120.554	92.306	2.954		390.221		
TSB(10^3 t)	573.256	1,058.096	1,860.749	71.192			3,563.294	
Mean length (cm)	9.170	12.680	15.730	16.810				
Mean weight (g)	3.290	8.780	20.160	25.590				9.140
MSN 10^9	0.234	16.305	82.292	2.782	0.000			
MSB 10^3 t	3.247	236.918	1,759.544		0.000		2,070.924	

2013

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-6.5	10.186					10.186	10.186	1.000
6.5-7	8.291					8.291	8.312	1.000
7-7.5	3.504					3.504	3.956	1.130
7.5-8	11.225					11.225	20.094	1.790
8-8.5	34.139					34.139	69.361	2.030
8.5-9	63.985	0.880				64.864	149.768	2.310
9-9.5	78.883	2.105				80.988	234.595	2.900
9.5-10	38.741	4.463				43.204	139.350	3.230
10-10.5	36.395	11.147				47.542	184.942	3.890
10.5-11	16.104	18.379				34.483	153.844	4.460
11-11.5	10.424	25.355				35.779	189.028	5.280
11.5-12	5.573	24.376	0.853			30.802	191.268	6.210
12-12.5	4.156	24.832	0.605	0.663		30.257	221.154	7.310
12.5-13	2.471	22.848	2.145			27.464	226.595	8.250
13-13.5	1.031	18.811	5.269			25.111	239.314	9.530
13.5-14	0.575	13.894	6.759	0.286		21.515	234.084	10.880
14-14.5	0.213	12.320	8.553	0.320		21.406	268.111	12.520
14.5-15		8.680	9.011	0.290		17.981	258.500	14.380
15-15.5		4.376	8.282	0.517		13.176	215.487	16.350
15.5-16		3.490	9.162	0.357		13.009	240.632	18.500
16-16.5		1.956	6.109	1.044		9.110	194.917	21.400
16.5-17		0.648	4.884	2.193		7.725	182.406	23.610
17-17.5		0.444	3.004	1.476		4.924	133.497	27.110
17.5-18		0.031	2.676	3.014		5.721	166.779	29.150
18-18.5		0.009	0.350	0.289		0.648	21.270	32.830
18.5-19				0.492		0.492	17.608	35.760
19-19.5					0.030	0.030	1.171	39.000
19.5-20					0.022	0.022	0.771	35.000
TSN(10^9)	325.897	199.043	67.662	10.942	0.052	603.596		
TSB(10^3 t)	993.800	1,602.118	1,115.570	263.568	1.942		3,976.998	
Mean length (cm)	9.010	12.140	14.820	16.340	19.500			
Mean weight (g)	3.050	8.050	16.490	24.090	35.000			6.590
MSN 10^9	0.213	31.955	52.031	9.992	0.052			
MSB 10^3 t	2.672	485.598	958.534	252.315	1.942		1,701.148	

2014

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-6.5	1.414					1.414	1.414	1.000
6.5-7	3.037					3.037	3.319	1.090
7-7.5	7.652					7.652	10.243	1.340
7.5-8	9.186	1.005				10.191	16.422	1.610
8-8.5	9.534					9.534	19.830	2.080
8.5-9	16.562					16.562	42.712	2.580
9-9.5	17.270	0.374				17.645	52.849	3.000
9.5-10	13.522	0.515				14.037	49.521	3.530
10-10.5	11.539	1.522				13.061	53.074	4.060
10.5-11	7.084	2.441				9.525	46.961	4.930
11-11.5	3.270	7.976	0.326			11.573	67.584	5.840
11.5-12	1.400	9.416	0.228			11.043	70.571	6.390
12-12.5	0.573	11.472	0.461			12.505	93.735	7.500
12.5-13	0.283	12.514	1.244			14.041	116.278	8.280
13-13.5	0.299	12.840	2.076			15.215	146.137	9.600
13.5-14	0.134	7.626	2.686			10.446	114.368	10.950
14-14.5		5.582	4.425	0.030		10.037	126.560	12.610
14.5-15		3.807	7.483	0.028		11.317	164.813	14.560
15-15.5	0.096	1.920	3.893	0.094		6.002	97.961	16.320
15.5-16		1.198	5.718	0.291		7.207	132.663	18.410
16-16.5		0.609	3.179	0.481		4.269	87.979	20.610
16.5-17		0.140	2.851	0.303		3.294	76.622	23.260
17-17.5		0.106	0.964	0.187		1.257	33.120	26.350
17.5-18		0.077	0.709	0.114		0.900	25.244	28.060
18-18.5		0.025	0.323	0.147		0.495	14.784	29.870
18.5-19			0.013			0.013	0.385	30.410
19-19.5			0.001			0.001	0.038	38.000
TSN(10^9)	102.855	81.165	36.581	1.673		222.274		
TSB(10^3 t)	314.608	723.444	589.628	37.507			1,665.187	
Mean length (cm)	8.860	12.480	14.780	16.280				
Mean weight (g)	3.060	8.910	16.120	22.410				7.490
MSN 10^9	0.096	13.463	29.559	1.673	0.000			
MSB 10^3 t	1.567	200.711	520.761	37.121	0.000		760.168	

2015

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	0.786					0.786	0.786	1.000
7-7.5	0.620					0.620	0.633	1.020
7.5-8	1.227					1.227	1.736	1.420
8-8.5	1.579					1.579	3.290	2.080
8.5-9	2.356					2.356	5.485	2.330
9-9.5	2.974					2.974	8.868	2.980
9.5-10	4.603					4.603	16.398	3.560
10-10.5	7.050	0.181				7.231	29.387	4.060
10.5-11	8.491	0.303				8.794	40.273	4.580
11-11.5	6.151	1.028				7.179	39.129	5.450
11.5-12	2.126	2.261	0.058			4.446	28.179	6.340
12-12.5	1.084	4.502	0.046			5.632	42.068	7.470
12.5-13	0.742	5.540	0.060			6.342	53.785	8.480
13-13.5	0.184	7.460	0.384			8.028	80.333	10.010
13.5-14	0.021	8.058	0.589			8.668	99.682	11.500
14-14.5	0.024	6.313	1.277			7.614	98.271	12.910
14.5-15	0.001	3.266	2.225	0.152		5.645	85.444	15.140
15-15.5		1.753	3.026	0.087		4.866	84.528	17.370
15.5-16		0.902	2.034	0.225		3.161	61.455	19.440
16-16.5		0.724	1.688	0.180		2.592	58.893	22.720
16.5-17		0.104	0.989	0.104		1.197	30.811	25.730
17-17.5		0.071	0.405	0.184		0.660	18.179	27.540
17.5-18		0.023	0.094	0.012		0.129	4.035	31.290
18-18.5			0.010	0.026		0.036	1.229	34.240
18.5-19				0.008		0.008	0.280	34.000
TSN(10^9)	40.020	42.489	12.886	0.980		96.375		
TSB(10^3 t)	168.429	468.255	234.395	22.078			893.157	
Mean length (cm)	9.970	13.240	15.060	15.900				
Mean weight (g)	4.210	11.020	18.190	22.530				9.270
MSN 10^9	0.026	13.156	11.749	0.980	0.000			
MSB 10^3 t	0.334	200.725	220.520	21.607	0.000		443.125	

2016

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
8-8.5	2.519					2.519	4.212	1.670
8.5-9	3.075					3.075	6.150	2.000
9-9.5	3.404					3.404	8.876	2.610
9.5-10	6.332					6.332	19.703	3.110
10-10.5	3.175					3.175	11.412	3.590
10.5-11	2.392	0.021				2.413	10.297	4.270
11-11.5	2.273					2.273	11.895	5.230
11.5-12	2.220	0.085				2.305	14.223	6.170
12-12.5	4.565	0.391				4.957	35.998	7.260
12.5-13	1.242	0.346				1.587	13.163	8.290
13-13.5	0.718	0.730				1.448	13.999	9.670
13.5-14	0.372	0.937	0.011			1.320	14.553	11.020
14-14.5	0.037	1.856	0.142			2.035	27.656	13.590
14.5-15	0.029	1.021	0.102			1.152	17.881	15.520
15-15.5	0.011	1.056	0.113	0.017		1.197	21.030	17.570
15.5-16		0.575	0.416			0.992	20.324	20.490
16-16.5		0.561	0.455	0.088		1.105	24.748	22.400
16.5-17		0.153	0.321	0.009		0.483	12.320	25.520
17-17.5		0.065	0.511	0.006		0.582	17.155	29.470
17.5-18		0.007	0.157	0.024		0.188	6.093	32.420
18-18.5			0.095			0.095	3.540	37.150
18.5-19		0.009	0.044			0.053	1.950	36.650
19-19.5			0.007			0.007	0.328	44.600
TSN(10^9)	32.365	7.813	2.375	0.144		42.696		
TSB(10^3 t)	141.917	113.244	58.776	3.567			317.505	
Mean length (cm)	10.200	14.180	16.190	16.210				
Mean weight (g)	4.380	14.490	24.750	24.820				7.440
MSN 10^9	0.077	5.304	2.364	0.144	0.000			
MSB 10^3 t	1.149	90.371	58.051	3.445	0.000		153.024	

2017

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
7-7.5	0.379					0.379	0.379	1.000
7.5-8	0.731					0.731	1.251	1.710
8-8.5	2.090					2.090	3.597	1.720
8.5-9	8.546					8.546	19.790	2.320
9-9.5	18.810					18.810	51.896	2.760
9.5-10	20.206					20.206	63.516	3.140
10-10.5	20.524	1.192				21.716	80.631	3.710
10.5-11	16.207	0.627				16.835	74.090	4.400
11-11.5	12.183	1.753				13.935	70.344	5.050
11.5-12	5.475	3.407				8.882	53.586	6.030
12-12.5	3.460	7.248				10.708	76.774	7.170
12.5-13	1.569	10.505				12.074	100.395	8.320
13-13.5	1.392	14.958				16.350	155.157	9.490
13.5-14	0.524	11.532	0.229			12.285	131.861	10.730
14-14.5	1.015	14.520	0.230			15.765	195.573	12.410
14.5-15	0.402	14.354	0.302			15.058	216.652	14.390
15-15.5	0.151	13.056	0.769			13.977	228.283	16.330
15.5-16	0.165	11.006	1.893			13.064	242.387	18.550
16-16.5	0.098	7.320	2.267	0.053		9.738	207.391	21.300
16.5-17		4.055	2.276	0.078		6.408	151.299	23.610
17-17.5		2.626	2.568			5.194	139.756	26.910
17.5-18		0.874	1.292	0.062		2.228	65.173	29.250
18-18.5		0.275	1.550	0.067		1.892	62.570	33.080
18.5-19		0.110	0.593	0.064		0.766	26.129	34.110
19-19.5		0.036	0.139	0.036		0.212	8.223	38.780
19.5-20			0.035			0.035	1.370	38.830
20-20.5								
20.5-21								
21-21.5				0.004		0.004		
TSN(10^9)	113.927	119.454	14.143	0.359		247.887		
TSB(10^3 t)	467.781	1,606.371	344.226	9.694			2,428.072	
Mean length (cm)	10.040	14.020	16.540	17.500				
Mean weight (g)	4.110	13.450	24.340	26.970				9.800
MSN 10^9	1.832	68.232	13.914	0.363	0.000			
MSB 10^3 t	26.008	1,166.235	342.040		0.000		1,544.804	

2018

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
8-8.5	5.489					5.489	12.181	2.220
8.5-9	4.866					4.866	12.733	2.620
9-9.5	4.728					4.728	14.310	3.030
9.5-10	5.107	0.001				5.109	18.191	3.560
10-10.5	6.686	0.006				6.692	27.811	4.160
10.5-11	6.669	0.007				6.677	32.798	4.910
11-11.5	11.356	0.202				11.557	64.655	5.590
11.5-12	7.090	0.503	0.062			7.655	49.651	6.490
12-12.5	4.098	2.568				6.666	50.139	7.520
12.5-13	1.507	3.993	0.077			5.576	49.251	8.830
13-13.5	0.744	8.784	0.459			9.987	102.960	10.310
13.5-14	0.356	8.739	0.266			9.361	109.230	11.670
14-14.5	0.276	10.679	1.982			12.937	170.637	13.190
14.5-15	0.020	10.280	1.950			12.250	186.034	15.190
15-15.5		6.786	3.134			9.920	171.752	17.310
15.5-16		3.560	3.249			6.809	132.144	19.410
16-16.5		2.453	2.532	0.066		5.051	111.703	22.120
16.5-17		0.590	1.995	0.076		2.661	67.022	25.190
17-17.5		0.817	2.123	0.054		2.994	86.612	28.920
17.5-18		0.174	1.512	0.055	0.002	1.743	57.931	33.240
18-18.5		0.047	0.924	0.085		1.055	36.623	34.700
18.5-19		0.032	0.946	0.003		0.981	36.014	36.710
19-19.5			0.141	0.004		0.145	6.593	45.460
19.5-20			0.176	0.001		0.177	8.166	46.180
TSN(10^9)	58.992	60.221	21.528	0.344	0.002	141.087		
TSB(10^3 t)	287.125	833.676	484.413	9.863	0.064		1,615.140	
Mean length (cm)	10.280	14.010	15.840	17.080	17.500			
Mean weight (g)	4.870	13.840	22.500	28.680	37.000			11.450
MSN 10^9	0.296	35.419	20.664	0.344	0.002			
MSB 10^3 t	3.940	584.921	472.318	10.046	0.058		1,071.230	

2019

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	0.080					0.080		
7-7.5	1.285					1.285	1.747	1.360
7.5-8	1.871					1.871	2.834	1.510
8-8.5	1.079					1.079	2.180	2.020
8.5-9	1.833	0.007				1.840	4.516	2.450
9-9.5	1.372	0.037				1.409	4.084	2.900
9.5-10	1.424	0.008				1.432	5.028	3.510
10-10.5	1.499					1.499	6.308	4.210
10.5-11	1.577	0.016				1.593	7.808	4.900
11-11.5	0.869	0.147	0.053			1.069	5.999	5.610
11.5-12	1.077	0.139				1.217	7.674	6.310
12-12.5	0.921	0.300				1.221	9.298	7.620
12.5-13	0.520	0.403	0.016			0.939	8.288	8.830
13-13.5	0.759	0.851	0.025			1.635	16.494	10.090
13.5-14	0.551	1.563	0.265			2.379	27.415	11.520
14-14.5	0.522	1.095	0.043			1.660	21.648	13.040
14.5-15	0.334	1.387	0.109	0.069		1.900	28.078	14.780
15-15.5	0.150	1.048	0.263	0.002		1.464	24.532	16.760
15.5-16	0.010	1.022	1.331	0.085		2.448	46.401	18.960
16-16.5	0.030	0.873	1.048	0.119		2.070	43.923	21.220
16.5-17	0.003	0.404	1.472	0.379	0.012	2.271	52.729	23.220
17-17.5		0.050	0.779	0.268		1.097	28.977	26.400
17.5-18		0.074	0.668	0.205		0.947	28.391	29.970
18-18.5		0.015	0.572	0.128		0.715	23.085	32.290
18.5-19		0.003	0.054	0.022		0.079	2.753	34.990
19-19.5			0.024	0.008		0.032	1.215	37.830
19.5-20					0.006	0.006	0.245	38.000
20-20.5				0.006		0.006	0.265	41.000
20.5-21					0.000	0.000		
TSN(10^9)	17.765	9.443	6.722	1.292	0.019	35.240		
TSB(10^3 t)	86.621	137.208	154.950	32.676	0.457		411.912	
Mean length (cm)	9.990	14.270	16.240	16.760	16.500			
Mean weight (g)	4.900	14.530	23.050	25.290	17.500			11.720
MSN 10^9	1.049	5.973	6.363	1.292	0.019			
MSB 10^3 t	15.157	103.799	150.076	32.683	0.526		302.240	

2020

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6.5-7	0.496					0.496	0.496	1.000
7-7.5	2.713					2.713	3.147	1.160
7.5-8	12.491	0.115				12.606	19.399	1.540
8-8.5	49.184	0.055				49.239	92.598	1.880
8.5-9	54.738					54.738	120.219	2.200
9-9.5	66.607	0.211				66.818	178.782	2.680
9.5-10	47.503	0.842				48.345	163.472	3.380
10-10.5	44.138	1.031				45.168	178.262	3.950
10.5-11	43.325	0.623				43.948	206.020	4.690
11-11.5	20.613	0.387				21.000	117.043	5.570
11.5-12	12.615	0.294	0.005			12.914	87.782	6.800
12-12.5	6.473	1.786	0.032			8.291	63.272	7.630
12.5-13	3.186	0.885				4.071	36.150	8.880
13-13.5	1.735	2.231	0.061			4.028	41.633	10.340
13.5-14	1.034	2.232	0.095			3.361	42.595	12.680
14-14.5	0.572	3.190				3.762	56.184	14.940
14.5-15	0.207	4.745	0.309			5.260	85.289	16.210
15-15.5	0.053	3.453	0.270			3.775	70.549	18.690
15.5-16		2.644	0.513	0.102		3.258	70.251	21.560
16-16.5		2.801	0.829	0.027		3.657	86.089	23.540
16.5-17		1.659	0.972	0.178		2.810	73.603	26.190
17-17.5		0.803	0.522	0.108	0.026	1.458	40.051	27.470
17.5-18		0.354	0.227	0.306		0.888	28.494	32.090
18-18.5		0.086	0.351	0.066		0.502	17.095	34.060
18.5-19		0.052	0.035	0.040		0.127	4.676	36.830
19-19.5				0.029		0.029	1.246	43.560
TSN(10^9)	367.680	30.478	4.221	0.855	0.026	403.260		
TSB(10^3 t)	1,271.364	479.633	107.198	25.625	0.578		1,884.398	
Mean length (cm)	9.420	14.050	16.160	17.130	17.000			
Mean weight (g)	3.460	15.740	25.400	29.970	22.600			4.670
MSN 10^9	0.831	19.786	4.028	0.855	0.026			
MSB 10^3 t	12.877	393.733	100.967	25.229	0.703		533.527	

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Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
7-7.5	3.193					3.193	4.266	1.340
7.5-8	5.342					5.342	10.006	1.870
8-8.5	17.791					17.791	40.262	2.260
8.5-9	27.932	0.923				28.855	75.862	2.630
9-9.5	53.775	2.790				56.565	171.077	3.020
9.5-10	58.506	6.097				64.603	221.783	3.430
10-10.5	31.447	14.975				46.422	186.405	4.020
10.5-11	15.676	43.470				59.146	282.518	4.780
11-11.5	4.573	39.573				44.146	241.765	5.480
11.5-12	2.850	40.500	0.028			43.378	277.593	6.400
12-12.5	1.352	34.196				35.548	264.378	7.440
12.5-13	0.751	31.795	0.115			32.661	285.043	8.730
13-13.5	0.400	26.186	0.334			26.920	273.514	10.160
13.5-14	0.104	18.402	0.505			19.011	224.570	11.810
14-14.5	0.082	15.792	0.357			16.231	215.543	13.280
14.5-15		13.237	0.637			13.873	214.843	15.490
15-15.5		14.201	0.258			14.459	251.175	17.370
15.5-16		9.747	1.487			11.234	223.009	19.850
16-16.5		6.212	0.737			6.949	154.838	22.280
16.5-17		6.709	0.349			7.059	176.593	25.020
17-17.5		2.733	1.065	0.010		3.809	105.377	27.670
17.5-18		1.095	0.402			1.497	48.095	32.130
18-18.5		0.180	0.904			1.085	36.458	33.610
18.5-19		0.115				0.115	4.303	37.370
19-19.5		0.034	0.101	0.001		0.136	5.376	39.460
19.5-20				0.021		0.021		
20-20.5				0.000		0.000		
TSN(10^9)	223.775	328.964	7.279	0.032		560.049		
TSB(10^3 t)	754.354	3,078.770	161.240	0.286			3,994.651	
Mean length (cm)	9.290	12.330	15.800	17.130				
Mean weight (g)	3.370	9.360	22.150	26.060				7.130
MSN 10^9	0.082	70.056	6.297	0.032	0.000			
MSB 10^3 t	1.091	1,283.705	150.533		0.000		1,435.609	

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An iterative approach for removing very large catches from swept-area data; a case study on capelin in the Barents Sea ecosystem survey

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Abstract

Some pelagic schooling fish may also be distributed close to the seabed. If they cannot be resolved from the seabed echo when using acoustics for stock size estimation, it leads to underestimation of the total stock size. For such stocks, using bottom trawl and calculating the number of fish near the bottom by swept-area techniques may be a solution. However, a problem frequently encountered in trawl surveys is that a few very large catches may lead to the sample mean being an over-estimate of the population mean. Capelin is a typical example of a species where this problem occurs due to its schooling behavior and patchy distribution. Detection and removal of outliers can be used when analyzing skewed distributions. Here, we present a systematic method for such outlier removal, using the Barents Sea capelin stock as a test case. The Barents Sea capelin stock is assessed based on the Barents Sea ecosystem survey in the autumn; a multipurpose survey with both acoustic measurements and bottom trawl sampling. The method is an iterative approach where the quality of the combined swept-area time series and acoustic series is validated in steps, removing the highest catches observed from the entire swept-area data gradually, and validating the result against consistency in abundance at age for consecutive years in the time series (internal consistency). The results show that the quality of the estimates improves when removing the largest outliers in the time series, and that the quality stabilizes when even more outliers are removed.

Introduction

When abundant, capelin is the dominating pelagic species in the Barents Sea in terms of biomass and the stock has been systematically monitored with acoustic surveys since 1972 (Eriksen at al. 2018). Since 2004 the most important capelin survey has been the joint Norwegian/Russian ecosystem survey in the Barents Sea (BESS) which is conducted annually during August-October. The acoustic estimates of capelin from BESS form the basis for the annual ICES catch advice (ICES 2021a) and the survey estimates are regarded as absolute, i.e. reflecting the true abundance and biomass (ICES 2021b; Eriksen at al. 2018). However, it is recognized that these probably are under-estimates since an unknown proportion of the capelin stock is distributed in the near-bottom acoustic dead zone (so close to the seabed that they cannot be observed on the echosounder, see e.g. Ona and Mitson 1996). Moreover, trawl sampling indicates that the capelin close to the bottom tend to be older and larger than the capelin higher in the water column, a phenomenon that has also been observed in the Gulf of Alaska (McGovan et al. 2018). Such depth-dependent age composition is expected to cause more severe under-estimation of the oldest age groups compared to the younger since the former have a higher probability to occur in the acoustic dead-zone.

The BESS has multiple objectives in addition to measuring the capelin stock acoustically, and one of these is swept-area estimation of demersal fish (Eriksen at al. 2018). Capelin is frequently caught in the demersal trawl which makes it possible to make swept-are estimates for this pelagic species as well. A way forward to handle the problem with underestimates due to the acoustic dead-zone is to combine the swept-area estimate with the acoustic estimate. Such an approach has been used for walleye pollock in the Bering Sea (Kotwicki et al. 2013; Kotwicki et al. 2017) and cod and haddock in the Barents Sea (Ono et al. 2017). However, a problem with trawl surveys is the occasional occurrence of very large catches which have a large effect on the estimate, often causing an over-estimate (Pennington 1996; Kappenman 1999; Syrjala 2000). This problem is expected to be more common for schooling species, like capelin, since the probability of high catches will be higher than for less schooling species like cod and haddock.

In this work, acoustic and swept-area estimates are combined in a rather simple way by adding them. In other words, the effective fishing height of the bottom trawl is assumed to correspond to the vertical extension of the acoustic blind zone close to the bottom. Using internal consistency as an objective way of assessing the quality of a time series of abundance estimates, we evaluate whether this approach has promise. Internal consistency is also used to explore the problem with occasionally very large catches in the swept-area data. An iterative approach is used where the outliers are removed gradually, starting with the highest. After each such removal the internal consistency is calculated with the aim of finding an appropriate outlier cut-off limit.

Material and Methods

In this work, data from the joint Norwegian/Russian ecosystem survey in the Barents Sea (BESS) is used. The survey is described in Eriksen et al. (2018) and in the annual survey reports, the latest of these being Prozorkevich and van der Meeren (2022). BESS in its current form has been conducted annually since 2004. The acoustic estimates of capelin in numbers at age have recently been re-calculated with the software Stox (WD capelin monitoring and biomass estimation in autumn) and these were used in this work. Data from bottom trawl were taken from the IMR database, since the swept-area estimates had to be made from scratch (see below).

The swept-area method
As described above, it is assumed that the effective fishing height of the bottom trawl corresponds to the vertical extension of the near-bottom acoustic dead zone. Thus, the bottom trawl based swept-area estimate can be added to the acoustic estimate to produce a so-called composite estimate of total capelin abundance. The principles in the swept-area method are as follows: In each bottom trawl haul, an observation of capelin density is obtained based on the number caught divided by the estimated area swept. An estimate of the total abundance (bottom component) can then be obtained by taking the average of the density observations and multiplying this with the total area covered during the survey. More specifically, the horizontal fishing width of the trawl was assumed constant at 25 m, and this correspond approximately to the wing spread of the trawl (Campelen 1800). The total area covered each year was roughly estimated based on the outer limit of the area containing trawl positions, and these areas are showed in Table 1. Only one year and older capelin were used in the calculations. This corresponds approximately to total length greater than 7.5 cm. Density in a trawl haul was estimated by (1) 0.5 cm length group and (2) density of all individuals larger than 7.5 cm. The latter (2) was used to calculate an outlier index for each trawl haul with density larger than zero: density in the trawl haul divided by the median density of non-zero densities in the same year/survey. Example: if the density in a trawl haul is two times greater than the median, then the outlier index is 2. The use of these outlier indices is central to the present

study and described more later. The estimated densities by 0.5 cm length group were used to obtain a total estimate in numbers by length group (multiplying the average density by the area covered shown in Table 1). These estimates were then translated into numbers at age by using an age-length key; estimated proportions of each age group within each length group. An age length key was calculated for each year by using all aged capelin caught during the ecosystem survey and simply calculate the proportions of the different age groups in each length group.

The iterative approach

As described in the Introduction, a few very large observations can have a high impact on the estimates in swept-area surveys, such that the sample mean becomes on over-estimate. One possible solution to avoid this is very simple: remove the largest observations. The outlier index described above can be used as a generic measure of how large outlier a trawl haul represent. The principle in the iterative approach in this work is to remove the trawl hauls based on the value of the belonging outlier index and start from the top, i.e. first remove the trawl haul with the highest index and then the two trawl hauls with the two highest indices etc. For each such removal the quality of the time series with abundance estimates is explored and as quality measure we used internal consistency. Internal consistency, also termed within survey correlation, is found by calculating the correlation between the log-transformed estimated abundances at subsequent ages since a linear relationship is expected (Payne et al., 2009). In other words, internal consistency measures whether the relative cohort strengths are similar across survey years. If a cohort is measured to be strong one year it should also appear strong the following year. An example of how internal consistency is calculated is shown in Figure 1. The iterations are done on composite estimates of abundance, i.e. the sum of the swept-area estimates and acoustic estimates.

Results

Table 1 shows the number of valid hauls per year, the proportion of the hauls with catch of capelin larger than 7.5 cm and the estimated area covered. Around half of the hauls generally have catch of capelin. The internal consistency between ages (same cohorts) for different values of outlier cut-offs are shown in Table 2 and Figure 2. For all three age steps, higher internal consistencies are obtained with composite estimates compared with the acoustic estimates only. The relative increase in internal consistency is, however, smaller for age step 1-2 compared to age step 2-3 and 3-4. Moreover, the internal consistencies improve when the trawl hauls with the highest outlier indices are removed, but the pattern of improvement is different for the different age steps. For age step 1-2 there is an optimum in internal consistency when hauls with outlier indices above 1900 are removed which means that 13 observations are removed (Tab. 2). However, the curve of the internal consistency as a function of outlier cut-off limit is quite flat so the optimum is not very distinct. For age step 2-3 the internal consistency is highest when outlier indices above 4300 are removed, which means that three hauls are removed. For age step 3-4 the internal consistency is highest when outlier indices above 7150 are removed which means that only one observation is removed. For the two oldest age steps a second local optimum is obtained further to the right around 1200 as an outlier cut-off limit. However, these optima are not very distinct as the curves made of by the points are quite flat between cut-off limits 4200 to 900. For all three age steps the internal consistencies decrease after the optimum when removal of hauls above a gradually reduced limit continues, and gradually converges toward the value with the acoustic estimates only. The different optima means that a possible general cut-off limit which is appropriate for alle age steps may be within a range.

Figures 3-6 show the contribution of the swept-area part of the composite estimates per year for age 1 to 4 where the highest outliers are removed according to an outlier cut-off limit of 2250 which means that 10 observations are removed. The composite estimates are generally dominated by the acoustic part, but the swept-area part increase with age and are higher when the acoustic estimates are low. The average proportions of the swept area part are as follows: 0.87% (range: 0.1-3.24%) for age 1, 5.82% (range: 0.5-20.26%) for age 2, 10.75 (range: 0.81-36.57%) for age 3 and 4.03 (range: 0.71-8.77%) for age 4. The proportions are, however, affected most by the acoustic estimates.

Discussion

The internal consistencies of the BESS time series show that the survey is generally well able to track the relative cohort strengths of capelin. This applies to both the acoustic estimates alone and for the composite estimates. If the largest outliers are removed from the swept-area data the composite estimates obtain higher internal consistency but only slightly higher for the youngest ages. The swept-area parts of the composite estimates are also quite small for the youngest ages. It is a simple approach to use the sum of the acoustic and swept area abundance estimates, and more advanced statistical methods have been presented (Kotwicki et al. 2013; Kotwicki et al. 2017). Combining estimates from the two survey types is in principle problematic because of shortcomings of each survey method and the unknown catchability ratio between the two methods (Kotwicki et al. 2013). Treating the capelin estimates as absolute assumes that the two important scaling factors; the applied acoustic target strength and the horizontal fishing width of the bottom trawl are known, and this assumption is highly debatable. However, the results from our parsimonious method show that the quality of the time series improve when combining the two data sources and this is an important first step. The improvement was largest for the oldest fish, age step 3 to 4, and this was not unexpected since it has been observed that capelin near the bottom often is older than capelin higher in the water column. This phenomenon can also explain the larger proportions of the swept-area part in the composite estimates for age 3 and 4. Obtaining more correct abundance estimates for the older ages may improve the quality of the catch advice since these ages dominate in the commercial catches. Regarding internal consistency as a measure of quality in the time series with abundance estimates, this measure also relies on a set of assumptions, like constant total mortality (see Payne et al. 2009; Nøttestad et al. 2016). The degree to which these assumptions are violated for capelin in the Barents Sea will of course affect the quality of our results, since internal consistency is the central measure. For example, a variable and sometimes large proportion of 2-year-old and 3-year-old capelin disappears out of the population to spawn, and this leads to variable natural mortality.

An important assumption in this work is that the effective fishing height of the bottom trawl corresponds to the vertical extension of the near-bottom acoustic dead zone. This assumption may be wrong for several reasons. First, the actual size of the near-bottom acoustic dead zone is difficult to know and measure exactly and may be smaller than the vertical opening of the bottom trawl. The typical distance between the headline and ground gear of the bottom trawls used during BESS is around 4 m, while the near-bottom acoustic dead zone typically is lower than this (Mello and Rose 2009). However, the effective fishing height of the trawl may also be much larger than the size vertical trawl opening: if fish swim towards the bottom in response to noise generated by the trawling vessel then the effective fishing height will be larger (Hjellvik et al. 2003). The effective fishing height is then also expected to be higher for larger fish due to their higher swimming capacity (Hjellvik et al. 2003). A possible consequence of this is that some capelin, the larger ones in particular, may be measured both acoustically and with the bottom trawl creating an over-estimate. Another related problem is potential bias in the so-called allocation of trawl samples to the acoustic measurements. Both samples from bottom trawl and pelagic trawl are used in the process of converting acoustic energy to number of fish by length group. However, it varies whether the samples from the bottom trawl hauls have been used in the allocation as these are often not regarded as representative for the acoustic recordings. Since capelin near the bottom tends to be older than capelin higher in the water column these subjective choices might have led to under-estimation of the abundance of old capelin. The observation that the internal consistency is higher for composite estimates compared with the acoustic estimates may then partly be explained by this under-sampling of old capelin in the acoustic estimates. Systematic studies of different ways to allocate samples to the acoustic data would have been useful to explore this potential problem in more depth.

Regarding the swept-area method, a central assumption herein is that the effective fishing width of the trawl is known in order to be able to calculate the area swept (trawled distance multiplied by fishing width) (Dean et al. 2021). In this work the assumed effective horizontal fishing width of the trawl is 25 meter which corresponds to the actual horizontal trawl opening or so-called wing spread. Analogous to the issue with effective vertical fishing height described above, the effective horizontal fishing width may be higher due to herding of fish by the trawl doors and sweeps (the wire between the doors and trawl net) and larger fish seem to be herded more due to its higher swimming capacity (Engås and Godø 1989). The typical distance between the trawl doors is 50 meters during BESS, and the swept-area estimates of cod and haddock are sometimes corrected according to size-dependent sweep width (Johannessen et al. 2019). Due to its relatively small size capelin is expected to be less herded by the sweeps compared to larger demersal fish, but the magnitude of the problem is still unknown. If the effective horizontal fishing width of the trawl is higher than assumed the abundance will be over-estimated since larger are swept means lower density for a given number of fish caught.

The number of very large catches, i.e. those with the highest outlier indices, that had to be removed from the swept-area data in order to obtain the optimal internal consistency was very low for age steps 2-3 and 3-4, only one and three hauls. For age step 1-2 the number was higher as 13 hauls had to be removed. A possible explanation is that the outlier index, which is calculated on the basis of all capelin individuals older than one year, is heavily dominated by the catch of one year old fish. Other methods for calculated this index should then be investigated, like making separate outlier indices for each age step based on the catch of relevant length groups. It is also a possibility that the optima for age step 2-3 and 3-4 are artefacts and that the "real" optima are those lower local optima further to the right described in the results section. Rather than just removing extreme values, an alternative approach is to use statistical estimators that are more robust to extreme values than the mean can be applied (see e.g. Pennington 1996; Kappenman 1999). Such estimators have not been tested on the BESS swept-area data yet, however, as shown by (Syrjala 2000) they will not necessarily improve the abundance estimates.

To conclude, a composite estimate of the acoustic and swept-area estimates seems to be an improvement compared to the acoustic estimates alone, provided that some of the largest outliers in the swept-area data are removed. The swept-area parts of the composite estimates (sum of acoustic and swept-area) are generally low, but significant from a stock assessment perspective in some of the years for ages 2 and older.

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Tables

Table 1. Swept-area data from the joint Norwegian/Russian ecosystem survey in the Barents Sea: Number of valid bottom trawl hauls (#hauls), proportion of the hauls with catch of capelin larger than 7.5 cm (catch>0) and estimated area covered each year.

Year	#hauls	catch>0 (%)	area (nmi²)
2004	581	46	380000
2005	622	50	360000
2006	637	39	340000
2007	476	52	390000
2008	390	54	350000
2009	357	56	390000
2010	320	56	380000
2011	379	58	390000
2012	429	52	400000
2013	418	63	380000
2014	286	64	300000
2015	324	60	370000
2016	256	45	300000
2017	321	60	370000
2018	213	63	250000
2019	313	57	330000
2020	416	52	410000
2021	328	66	340000

Table 2. Internal consistency (Corr.) for different age steps and outlier cut-off limits (swept-area density observations above the limit are removed). The first line (aku only) is for acoustic estimates and all the lines below for composite estimates. The last column contains the number of observations removed (the total number of valid trawl hauls is 7066, see Tab. 1).

Cut-off	Corr. age 1-2	Corr. age 2-3	Corr. age 3-4	#obs removed
aku only	0.7281	0.7740	0.7259	
no cut	0.7150	0.7798	0.7433	0
7150	0.7294	0.8136	0.7904	1
5400	0.7320	0.8146	0.7904	2
4300	0.7319	0.8147	0.7852	3
4250	0.7267	0.7972	0.7732	4
3300	0.7280	0.7984	0.7731	5
3250	0.7290	0.7980	0.7730	6
3050	0.7311	0.7975	0.7742	7
2900	0.7333	0.7983	0.7745	8

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Cut-off	Corr. age 1-2	Corr. age 2-3	Corr. age 3-4	#obs removed
2400	0.7332	0.7993	0.7749	9
2350	0.7332	0.7993	0.7749	10
2250	0.7343	0.7984	0.7745	11
2150	0.7344	0.7988	0.7749	12
1900	0.7355	0.8009	0.7753	13
1850	0.7354	0.8005	0.7745	14
1650	0.7354	0.8008	0.7747	15
1550	0.7349	0.8017	0.7765	16
1400	0.7344	0.8025	0.7782	17
1250	0.7346	0.8035	0.7777	18
1150	0.7347	0.8033	0.7776	19
950	0.7346	0.8031	0.7769	20
900	0.7346	0.8032	0.7770	21
800	0.7305	0.7980	0.7728	24
750	0.7304	0.7979	0.7727	25
650	0.7302	0.7982	0.7732	26
600	0.7312	0.8008	0.7745	27
500	0.7304	0.7861	0.7600	28
450	0.7308	0.7867	0.7608	32
400	0.7308	0.7867	0.7608	34
350	0.7290	0.7792	0.7511	39
300	0.7299	0.7802	0.7442	43
250	0.7297	0.7800	0.7430	49
200	0.7301	0.7804	0.7387	59
150	0.7299	0.7772	0.7366	69
100	0.7291	0.7739	0.7334	94
50	0.7296	0.7756	0.7350	187
40	0.7296	0.7765	0.7365	218
30	0.7297	0.7766	0.7347	265
20	0.7298	0.7769	0.7339	357
10	0.7296	0.7771	0.7318	613
5	0.7291	0.7762	0.7295	942
1	0.7282	0.7743	0.7265	1934

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Figures

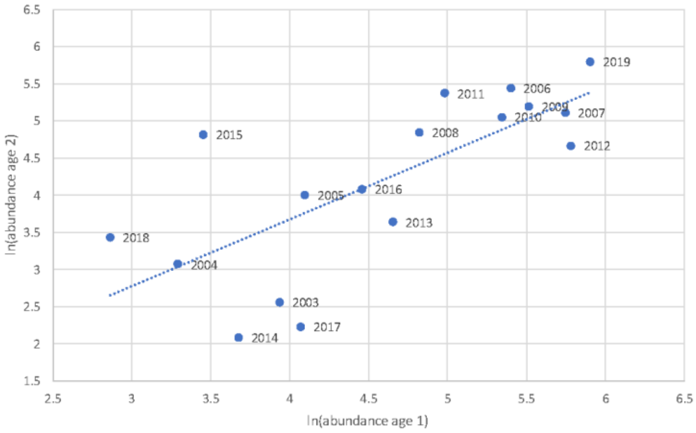

Figure 1. Internal consistency of BESS acoustic estimates of capelin between age 1 and age 2, represented by points with fitted line. The correlation is 0.73 and this number can be viewed as the quantitative measure of internal consistency. The points are labeled with year class.

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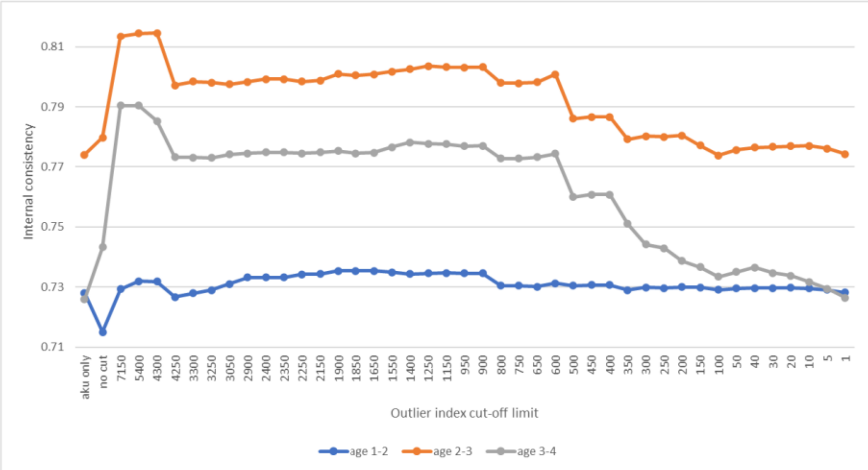

Figure 2. Outlier cut-off limit (swept-area density observations above the limit are removed) and internal consistency, one line of points for each age step. The first observation from the left is for the acoustic estimates only while the rest are for composite estimates. The data are also shown in Table 2.

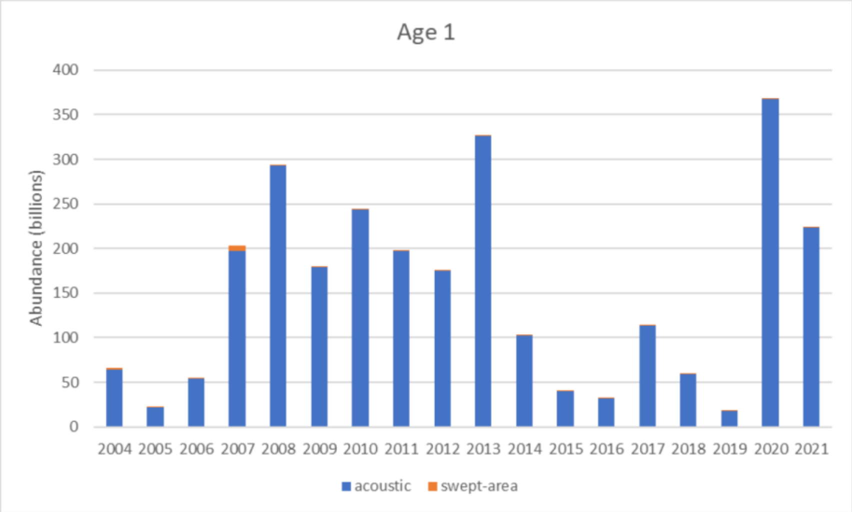

Figure 3. Composite estimates of one-year-old capelin from the joint Norwegian/Russian ecosystem survey in the Barents Sea. The density observations with an outlier index larger than 2250 are removed.

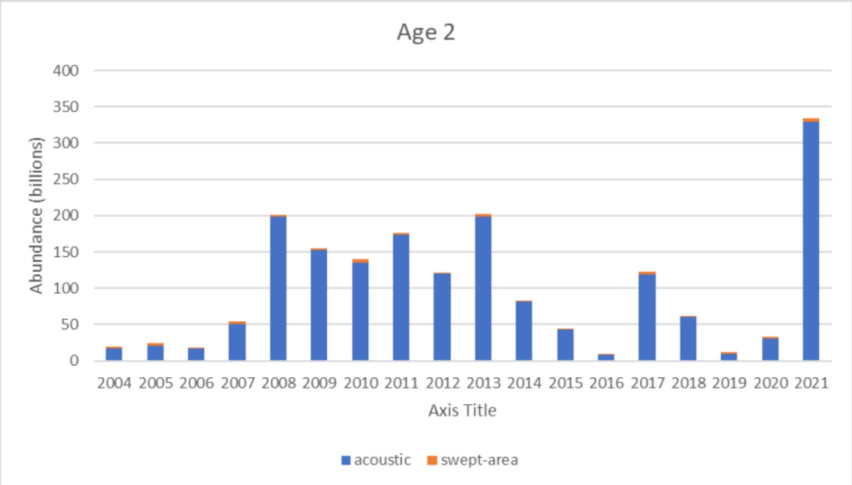

Figure 4. Composite estimates of two-year-old capelin from the joint Norwegian/Russian ecosystem survey in the Barents Sea. The density observations with an outlier index larger than 2250 are removed.

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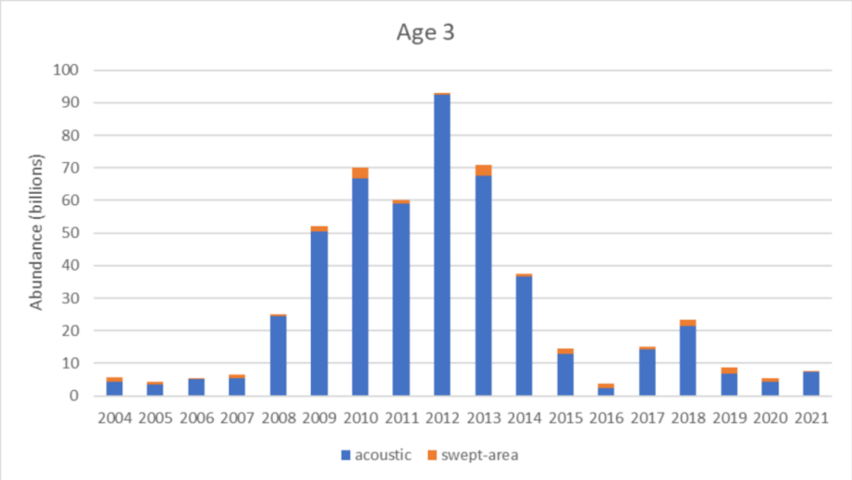

Figure 5. Composite estimates of three-year-old capelin from the joint Norwegian/Russian ecosystem survey in the Barents Sea. The density observations with an outlier index larger than 2250 are removed.

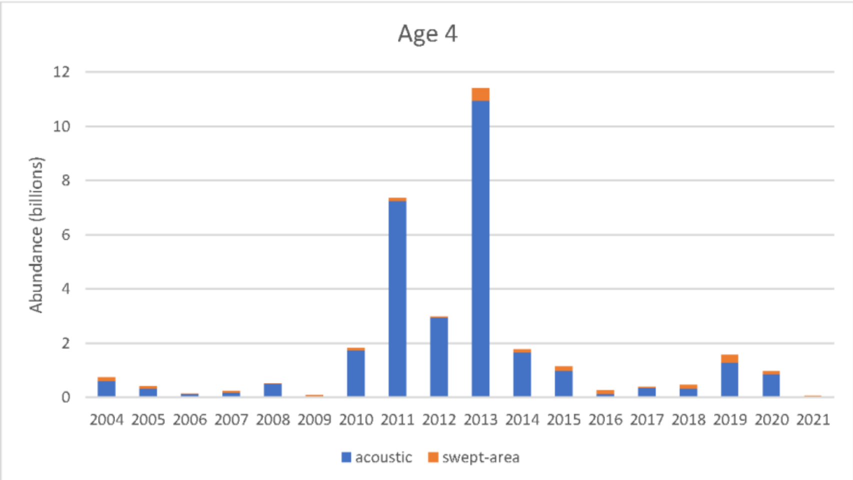

Figure 6. Composite estimates of four-year-old capelin from the joint Norwegian/Russian ecosystem survey in the Barents Sea. The density observations with an outlier index larger than 2250 are removed.

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Combining swept area indices and acoustic indices for Barents Sea capelin

Working document # BS2 to the ICES WKCAPELIN2022, Iceland 21-25 November 2022

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1 Introduction

Although capelin is a pelagic, schooling fish, it has been known for a long time that capelin may be caught in bottom trawl throughout the year in large parts of the Barents Sea (Gjøsæter 1998). In most cases, few individuals are caught, indicating that "bottom dwelling capelin" are normally found dispersed and in low quantities (Furset 2007) but in some cases large catches of capelin may be encountered. In such cases the question always arises whether the catch was taken at the bottom during the trawl haul or perhaps obtained when the trawl hit a pelagic school during setting or heaving. The fact that the capelin caught in bottom trawl are often larger than those caught with pelagic trawl suggests that there may be a special component of the capelin stock living permanently or often residing at or close to the sea floor (Gjøsæter 1998, Furset 2007). Seemingly the largest capelin are underestimated in the autumn acoustic survey and one possible reason for this underestimation may be that parts of this larger capelin stay near the sea floor and are partly inaccessible to the acoustic instruments.

From 2004, when the capelin investigations in autumn were merged with other investigations to form an ecosystem survey, systematic hauls with a demersal sampling trawl set in predefined positions spread over the total Barents Sea have become available, in addition to the acoustic investigations carried out during the same surveys. A time series of swept area estimates based on the demersal trawl hauls from these surveys was presented in a working document to the WKREDCAP data compilation workshop in 2021 (Gjøsæter et al. 2021). As mentioned above, a few large catches of capelin in the demersal trawl in some of the years in the time series influence the swept area estimates to a large degree. In a paper presented to the ICES capelin symposium in Bergen in October 2022 this problem was addressed (WD BS_1) and a systematic and objective method for discarding such outliers were proposed.

In this working document, a revised time series of swept area estimates is presented, together with a proposal for how to combine these with the acoustic estimates to form a composite estimate for use in future assessments is presented. In the revision of swept area estimates, the method for discarding outliers proposed in WD BS_1 is used. The whole estimation procedure is also rerun in StoX v. 3.5 (Johnsen et al 2019), based on the newest version of all data files. Where the estimates in Gjøsæter et al. (2021) were based on mean values from 500 bootstrap runs with StoX, the present series contain estimates based on the baseline runs, to be compatible with the acoustic estimates from the same surveys. These estimates do not vary consistently from those derived from the bootstrap runs.

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2 Material and methods

2.1 Survey description

The annual autumn Barents Sea ecosystem surveys (BESS) were started in 2004, as a continuation and merging of various survey time series, some going as far back as 1972 (Michalsen, Dalpadado et al. 2013, Eriksen, Gjøsæter et al. 2018). The survey is a joint survey carried out with three to five research vessels from Norway and Russia. From this survey, an acoustic stock size estimate is obtained, forming the only input to the present stock assessment model for Barents Sea capelin. Here, we report on a new time series of swept area estimates from the bottom trawl hauls during the same survey.

The bottom trawl hauls are conducted according to a survey design involving a regular station grid with about 30 nautical miles between stations. The coverage has varied somewhat over the years due to lack of ship time, restricted areas due to military activity, or other causes outside control of the survey organizers. The bottom trawl used is a Campelen 1800 shrimp trawl with a vertical opening of 3.5-4.0 m and a horizontal opening of about 25 m (Engås and Godø 1989). The duration of each haul is 15 minutes. The catches are sorted to species level and weighed, and from the catch of capelin a maximum of 100 capelin are length measured, while samples of age, sex, stomach fullness and maturity stage are taken from 25 fish.

2.2 Swept area indices

A stock abundance index series based on bottom trawl hauls at the annual autumn Barents Sea ecosystem survey (BESS, (Michalsen, Dalpadado et al. 2013, Eriksen, Gjøsæter et al. 2018)) was calculated using the StoX v 3.5 software (Johnsen, Totland et al. 2019). Trawl data were available from 2004, although the coverage in various parts of this area varied somewhat due to ship availability, weather conditions etc. The area is split into a number of strata developed for demersal fish on the survey (Johannesen et al. (2019) (Figure 1) and the stock abundance index is calculated for each stratum separately.

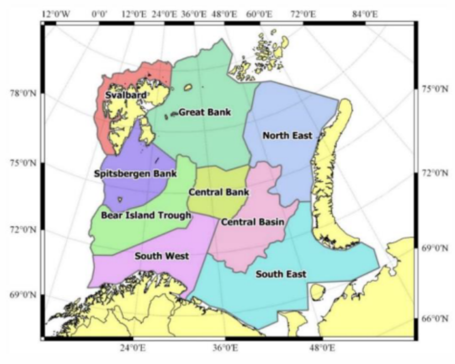

Figure 1 Strata system used for the swept-area estimation of capelin.

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2.2.1 *Swept area indices by length*

The swept area density (ρ, individuals per square nautical mile, inds nmi^{-2}) by stratum (k), station (s) and length group l (1/2 cm), is given by

$$\rho_{k,s,l} = f_{k,s,l}/sw, \tag{eqn 1}$$

where $f_{k,s,l}$ is the number of individuals standardized over a towing distance of 1 nmi by k, s and l, and *sw* is the swept width in nmis (25/1852).

The abundance (*N*, inds) by l and k is calculated using

$$N_{k,l} = \rho_{k,l} A_k, \tag{eqn 2}$$

where *A* is stratum area (nmi^2), and $\rho_{k,l}$ is the average swept area density by l and k, given by

$$\rho_{k,l} = (1/n)\sum_{s=1}^{n} \rho_{k,s,l}, \tag{eqn 3}$$

where n is number of stations.

2.2.2 *Swept area indices by age*

A two-stage conversion process is used to convert the abundance of fish by length group to abundance of fish by age group.

First, the abundance ($N_{k,l}$) by length group l (1 cm) and stratum k is distributed by the length-measured individuals (j) to generate so-called "Super-individuals" (super-individuals represent fractions of a total, our use corresponds to a probability based design where $w_{k,j,s,l}$ is the inverse of the inclusion probability for a single fish sample), each representing an abundance estimated as:

$$N_{k,j,s,l} = N_{k,l} w_{k,j,s,l}, \tag{eqn 4}$$

where

$$w_{k,j,s,l} = {}^{\rho_{k,s,l}}\Big/_{\left(\sum_{s=1}^{n} \rho_{k,s,l}\right)} \times {}^{1}\!/_{m_{k,s,l}} \tag{eqn 5}$$

and *m* is the number of length-measured individuals

Second, in instances where a super-individual is not aged, the missing age is filled in by a random data imputation. The imputation of missing age is principally carried out at the station level, randomly selecting the value from aged super-individuals within the same length group. If no aged super-individual is available at the station level, the imputation is attempted at strata level, or lastly on survey level. In instances where no age information is available at any level for a specific length group, the abundance estimate is presented with unknown age (Johnsen, Totland et al. 2019).

2.2.3 *Length and weight at age*

Length and weight at age was calculated using the weighting factors defined in eqn 5 (the "super - individuals").

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2.3 Swept area indices – settings in StoX

The processes included and the settings of parameters when running StoX for these swept area indices were given in Gjøsæter et al. (2021). The same settings were applied when making the revised time series presented here. The only difference is that instead of basing the reports on 500 bootstrap runs, the reports were based on the "superindividuals" dataset where missing age at length and individual weight at length were imputed as described in Gjøsæter et al. 2021).

2.4 Combining swept area estimates of capelin to the acoustic stock estimates

The suggestion is simply to add the numbers by age and length group estimated from bottom trawls to the numbers by age and length group estimated by acoustics. This method is simplistic and rests on several assumptions:

- that none of the capelin individuals caught in the bottom trawl were detected acoustically,
- that none of the individuals detected by acoustics were caught in the bottom trawls.
- that there is no herding effect by sweeps and doors (sweeping width = 25 m)
- that the fishing height of the trawl is the vertical trawl opening (ca 4 m)
- that there is no selection of capelin in the trawl

None of these assumptions are probably true. The motivation for using the method is that the combined estimate might be a better estimate of the total amount of capelin than is the acoustic estimate alone, presently used in the stock assessment, see WD BS_1.

In practical terms, the total number by age and length group from the swept area estimate is added to the total number by age and length group from the acoustic estimate.

It was concluded in WD_BS1 that a few large catches had huge impact on the total swept area estimates. It was suggested to use a method where the catches constituting the most extreme outliers in the time series were successively excluded until the internal consistency of the time series was optimized. This showed that only ten catches from the total time series had to be excluded; two from 2004, one from 2006, two from 2007, one from 2010, two from 2018, one from 2019, and one from 2020 (WD BS_1).

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3 Results

Main results from the calculations are shown in Table 1-3 and in Figure 2-5.

The abundance of capelin estimated from the demersal trawl catches (Table 1, Figure 2, basecase) varies from about 2 million to 10 million individuals. Most years, the estimates are around two-five million but, in two years, 2010 and 2013, the estimates are eight-ten million individuals. In Figure 3, the swept area abundance estimate is compared to the acoustic estimate for each of the years in the time series. The corresponding biomass estimates ranges from about 30 kt to 170 kt (Table 2, Figure 4). The maturing part of the swept area abundance estimate (taken to be the part of the estimate comprising the length groups equal to or larger than 14.0 cm) is shown in Table 3. In Figure 5, the swept area biomass estimate is compared to the acoustic estimate for each of the years in the time series.

To show the sensitivity of the swept area estimates to inclusion or exclusion of large catches, StoX was run on projects where all catches all years were included, and one where the ten catches prescribed in WD BS_1 were excluded (base case). The effect of replacing the original runs with these runs is shown in Figure 2 (abundance) and Figure 4 (biomass).

Table 1 Swept area abundance indices (million individuals). Basecase where ten catches were excluded according to the method outlined in WD BS_1

	Age 1	Age 2	Age 3	Age 4	Age 5	Sum 1-5 sw basecase
2004	1.344	2.709	1.735	0.143	0.002	5.934
2005	0.092	3.241	0.699	0.091	0.003	4.126
2006	0.176	0.830	0.486	0.016	0.001	1.509
2007	1.290	1.850	0.724	0.056	0.000	3.920
2008	1.011	2.908	0.588	0.004	0.001	4.513
2009	0.111	2.304	2.446	0.026	0.000	4.887
2010	0.180	2.962	5.138	0.074	0.000	8.353
2011	0.434	3.073	1.329	0.198	0.003	5.038
2012	0.333	0.700	0.967	0.027	0.000	2.027
2013	0.256	5.124	4.068	0.533	0.001	9.982
2014	0.138	1.059	1.159	0.112	0.000	2.467
2015	0.251	1.933	2.058	0.232	0.000	4.475
2016	0.669	2.179	2.245	0.062	0.000	5.155
2017	0.463	4.208	1.119	0.006	0.000	5.796
2018	0.715	2.773	3.113	0.220	0.000	6.821
2019	0.204	3.793	3.041	0.201	0.000	7.239
2020	0.075	0.886	0.909	0.053	0.000	1.924
2021	0.728	6.380	0.352	0.023	0.000	7.483

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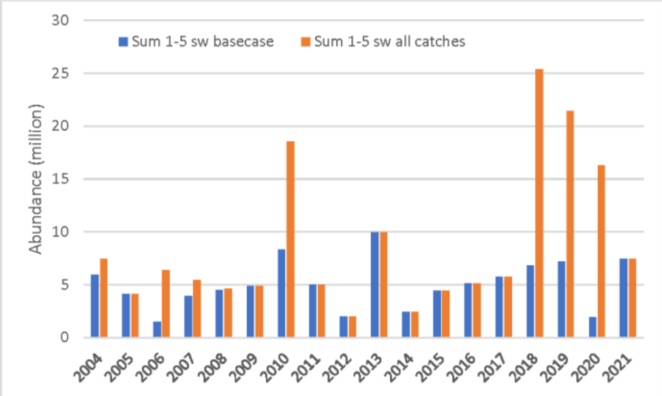

Figure 2. Time series of swept area estimates (abundance) of capelin. Basecase (ten catches excluded) compared to runs where all catches were included.

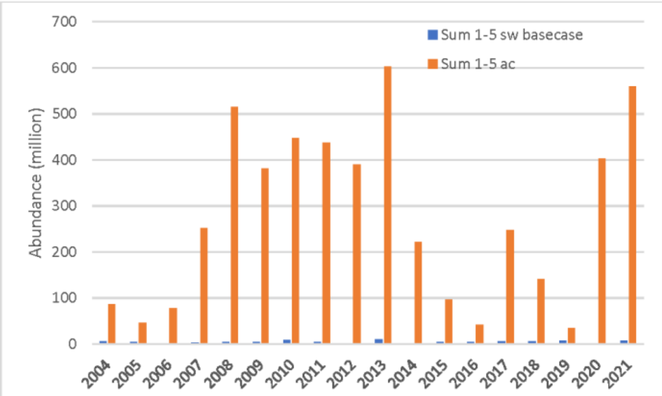

Figure 3. Time series of swept area estimates (abundance) of capelin and acoustic abundance estimates compared.

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Table 2 Swept area biomass indices (kilotonnes). Basecase, where ten catches were excluded according to the method outlined in WD BS_1

	Age 1	Age 2	Age 3	Age 4	Age 5	Sum 1-5 sw 10 excluded
2004	9.955	37.621	35.501	3.173	0.056	86.305
2005	0.523	49.980	12.427	1.569	0.066	64.565
2006	1.049	15.404	12.393	0.410	0.021	29.276
2007	9.928	32.956	19.827	1.638	0.000	64.348
2008	4.703	45.214	15.518	0.133	0.036	65.604
2009	0.560	43.693	62.033	0.654	0.000	106.940
2010	0.777	34.373	103.546	1.916	0.000	140.612
2011	1.672	37.741	27.234	5.018	0.103	71.767
2012	2.917	9.141	19.145	0.652	0.000	31.855
2013	1.470	76.013	79.995	12.720	0.036	170.234
2014	0.577	12.803	21.389	2.349	0.000	37.117
2015	1.146	27.622	41.488	5.692	0.010	75.957
2016	5.114	39.561	61.324	1.653	0.000	107.651
2017	2.849	65.072	28.520	0.157	0.000	96.598
2018	4.223	56.957	84.778	7.281	0.003	153.243
2019	1.532	65.170	74.813	5.449	0.000	146.964
2020	0.211	18.922	25.425	1.728	0.000	46.285
2021	3.231	91.291	8.156	0.510	0.007	103.195

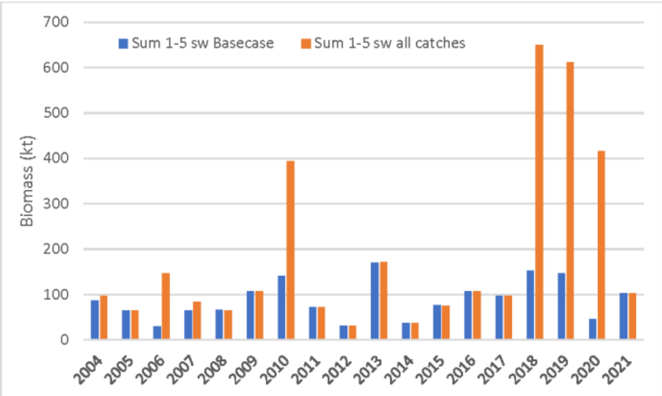

Figure 4. Time series of swept area biomass estimates. Basecase, where ten catches were excluded according to the method outlined in WD BS_1, compared to runs where all catches were included.

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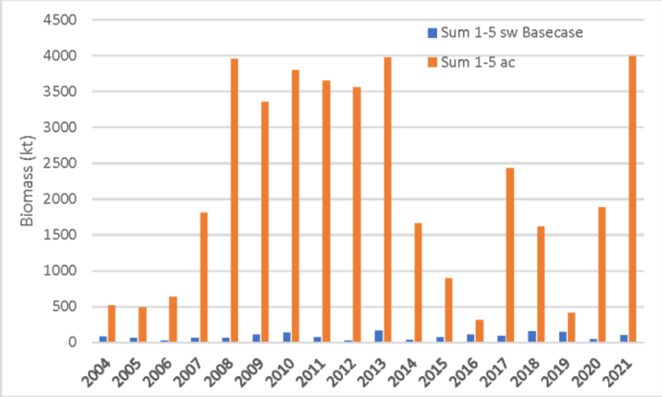

Figure 5. Time series of swept area estimates (biomass) of capelin and acoustic biomass estimates compared.

Table 3. Swept area abundance estimates of the maturing part of the stock (taken to be all individuals equal to or larger than 14.0 cm).

	N Age 1 >= 14 cm	N Age 2 >= 14 cm	N Age 3 >= 14 cm	N Age 4 >= 14 cm	N Age 5 >= 14 cm	Sum 1-5 >= 14 cm
2004	0.148	1.505	1.705	0.143	0.002	3.504
2005	0.000	2.531	0.672	0.091	0.003	3.297
2006	0.005	0.744	0.472	0.016	0.001	1.238
2007	0.056	1.602	0.724	0.056	0.000	2.438
2008	0.001	2.059	0.588	0.004	0.001	2.653
2009	0.001	1.601	2.439	0.026	0.000	4.067
2010	0.000	1.317	5.056	0.074	0.000	6.447
2011	0.001	1.665	1.290	0.198	0.003	3.157
2012	0.072	0.360	0.937	0.027	0.000	1.396
2013	0.002	3.507	3.961	0.533	0.001	8.004
2014	0.000	0.484	1.059	0.112	0.000	1.655
2015	0.000	1.238	2.023	0.232	0.000	3.494
2016	0.031	1.882	2.243	0.058	0.000	4.214
2017	0.032	3.148	1.117	0.005	0.000	4.301
2018	0.011	2.358	3.059	0.220	0.000	5.648
2019	0.000	3.350	3.004	0.201	0.000	6.556
2020	0.000	0.833	0.909	0.053	0.000	1.796
2021	0.000	3.394	0.330	0.021	0.000	3.745

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4 Discussion

As outlined in the Results section, the swept area estimates are based on some strong assumptions about the catchability of the trawl and its fishing width and height (see also WD BS_1). If combining acoustic estimates and swept area estimates by simply adding the two together, one would in addition have to assume that none of the capelin included in the swept area estimate was included in the acoustic estimate, and *vice versa*.

It is seen that in most years, the swept area estimates are small compared to the acoustic estimates (Figure 3 and 5), except for the years 2016 and 2019 where the swept area estimate constitutes a significant part of the total.

The sensitivity of the estimates to inclusion or exclusion of single catches are large (Figure 2 and 4). The fact that excluding only a few stations (of several hundred) changes the estimates significantly, is a clear signal that these estimates should be handled with caution.

On the other hand, the internal consistency of the time series has been shown to increase when the swept area estimates (with ten catches excluded) were added to the acoustic estimates (WD BS_1). This indicates that the acoustic estimate may not cover this component of the stock representatively.

It is also worth noting that a rather large proportion of the swept area estimate consists of capelin larger than 14 cm, i.e. fish that will be part of the spawning stock next spring.

Consequently, although an inclusion of an estimate of the capelin found near the sea floor in the stock assessment of capelin may be immature at this stage, further effort should be made to study how the swept area estimates can be made more robust, and how they best can be combined with the acoustic estimates to form a new basis for stock assessment and quota advice.

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WD_BS3 Autumn abundance estimation of BS capelin - Allocation of biological stations and estimation of sampling variance

Georg Skaret

Background

Estimates of Barents Sea capelin stock abundance are made annually based on acoustic-trawl monitoring data. Since 2004 the data collection has been done as part of the joint Russian/Norwegian Barents Sea Ecosystem Survey (BESS) conducted in August-October. In the Barents Sea capelin stock assessment, the BESS acoustic-trawl estimates are interpreted as absolute abundances and they are the only capelin stock abundance input data used in the assessment (JRN-AFWG, 2022). The method for biomass estimation is described in detail in 'WD Capelin monitoring and abundance estimation in autumn' on the sharepoint presented for the data evaluation workshop in December 2021.

In this WD we will focus on two aspects of the biomass estimation. Part 1 evaluates the selection of biological data to estimate length distributions used when converting acoustic backscattering to biomass. There is no standard procedure for station allocation in the BS capelin assessment today. A standard procedure would be advantageous and we evaluate two alternatives to the original station allocation. Part 2 relates to estimation of sampling variance in the survey. Presently a fixed annual CV of 0.2 by age group is used in the stock forecast, but this could be replaced with annual CV estimates based on the survey data.

Part 1 Selection of biological stations for biomass estimation

Sampling

Three types of trawl hauls which all sample capelin are carried out during BESS:

1) 15 minute demersal hauls at fixed positions using Campelen 1800 shrimp trawls with a vertical opening of 3.5-4 m.
2) 0-group pelagic hauls at fixed positions (same positions as the demersal hauls) using Harstad-trawl with a ca. 20x20 m opening. The trawl is deployed stepwise in depths of 0, 20 and 40 m with 10 minute sampling at each depth.
3) Pelagic target hauls at non-fixed positions on acoustic recordings using Harstad-trawl.

From all trawls, length and weight are measured (catch size permitting) for 100-300 capelin, and samples of age, sex, stomach fullness and maturity stage are taken from 25-50 fish from the trawl hauls. The frequency of each trawl haul type by year is shown in Fig. 1.

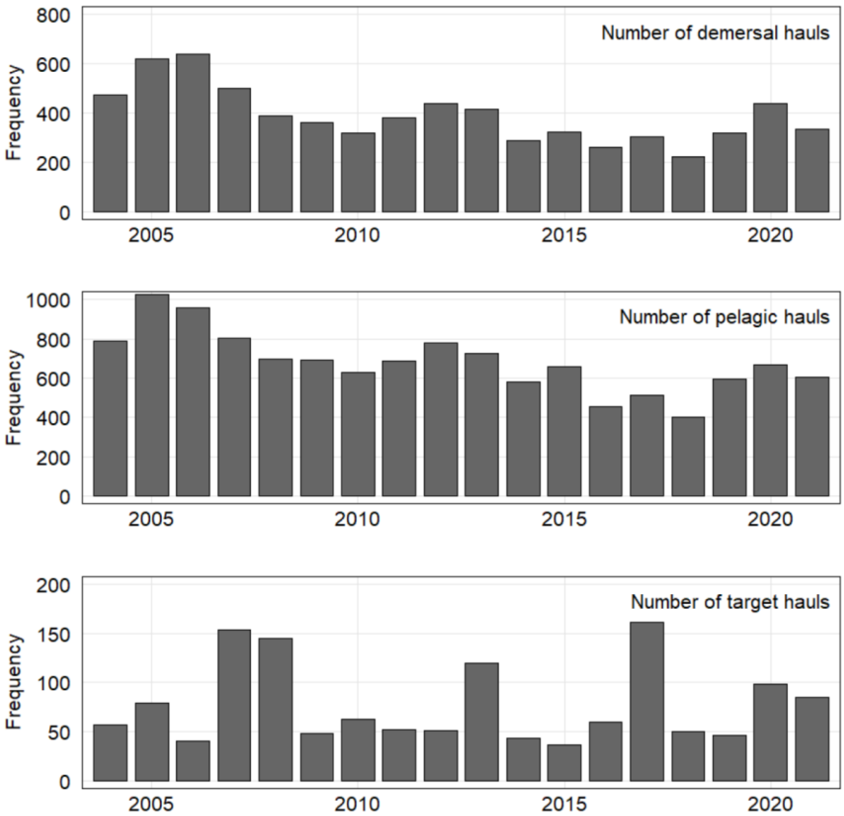

Fig. 1. Frequency of trawl hauls for the different trawl types for the BESS time series (2004-2021). Prior to 2004, the sampling design was different and dominated by target hauls.

Abundance estimation

The capelin length distributions are typically different for the different types of trawl hauls (see fig. 2). For the biomass estimation in Stox, there is a weighting of the length distribution from each haul according to the acoustic backscatter (in units of Nautical Area Scattering Coefficient; NASC; m^2/nmi^2) within a radius of 10 n.miles distance from the haul. The NASC-values are combined with the length distribution of a given biotic station to calculate a fish density as number per square nautical mile which is used as the weighting variable for each trawl station. Figure 3 shows the weighting of the hauls from the 2021 survey. The weighted stations are assigned to mean NASC for each acoustic transect (Primary Sampling Unit) by strata. That is, all the trawl stations within a given stratum are assigned to each transect within that stratum. In the rare cases when no trawl stations with capelin are present within a stratum, stations from neighbor strata are used. The length distribution from the trawl hauls are used as input for individual fish length (L) in the conversion from acoustic target strength (TS) to biomass which for Barents Sea capelin starts with the relation (Dommasnes and Røttingen, 1985):

$$TS = 19.1 \cdot logL - 74$$

More detail about the BS capelin biomass estimation can be found in 'WD Capelin monitoring and biomass estimation in the autumn'.

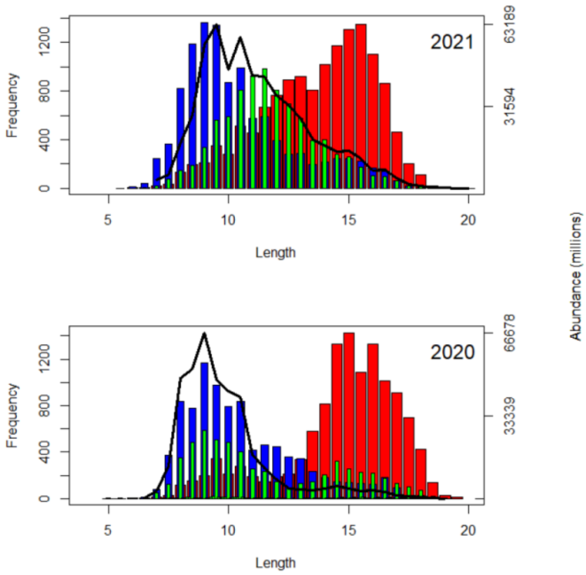

Figure 2. BS capelin length distribution for 2020 and 2021 from all trawl hauls with red bars indicating demersal hauls (fixed positions), blue bars pelagic 0-group hauls and green bars pelagic target hauls. The black line indicates estimated capelin length distribution from Stox (median run) with abundance given on the right-hand axis.

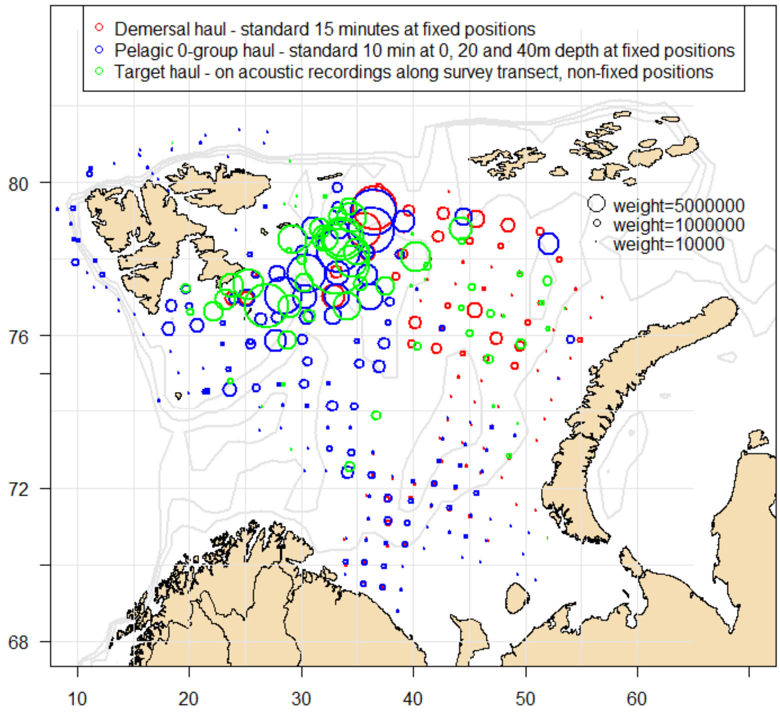

Figure 3. Overview of trawl samples included in the capelin biomass estimation in 2021. The colours of the circles refer to different types of hauls, and the size of the circles are proportional to the square root of the weighting factor (in the unit of number of individuals per square nautical mile).

Set-up of the exercise

In this exercise we modified the selection of stations allocated to the biomass estimation, re-estimated biomass and compared the results with the station selection used for the original estimate. We then evaluated the result by calculating the resulting internal consistency, i.e. correlation between age groups from one year to the next, similar to how it is done for swept area estimation described in WD_BS1. We remove data from the outlier survey year 2016 in the comparison. We compared three different set-ups:

1) **Set-up with the station selection that was used for the original estimate**
There is no standard procedure for selecting stations for allocation in the assessment, but all target hauls and all 0-group hauls are normally selected while it varies somewhat from year to year which demersal trawl hauls are selected.
2) **Set-up with all stations with capelin catch selected**
The most parsimonious approach is to include all stations with capelin catch under the assumption that they together provide a representative length distribution for the acoustic recordings.
3) **Set-up with only target hauls selected**
In this approach only target hauls after capelin are selected. These are typically carried out on conspicuous acoustic recordings. The assignment of trawl stations is done at stratum level, and with this set-up the strata with low abundances of capelin oftentimes do not have target hauls in them. In such cases, the three target stations closest geographically to a given stratum were selected from neighbour strata.

In the evaluation we simply correlated the abundance of age group *a* in year *y* with age group *a+1* in year *y+1,* using the Pearson product moment correlation.

Results

A comparison of age group abundance based on the three different allocations of stations is shown in Figure 4. For age groups 2, 3 and 4, mean abundance estimates from both the alternative allocations (all stations included and only target hauls included) are within the confidence bands of the original allocation for all years except 2013. For 1-year-olds, estimates using alternative station allocations are outside the confidence bands in 4 of the years.

Figure 5 shows the abundance at age for each year for the two alternatives relative to the alternative with the original station selection. When all stations are selected, the abundance of 1-year-olds is typically lower than the original allocation, while the abundance of 2-year-olds is similar and abundance of 3-year-olds is higher. When only target hauls are selected, the abundance of 2-year-olds is higher while the abundance of 1 and 3-year-olds is lower compared to original allocation. Figure 5 shows that estimates for 4-year-olds are very variable with the different allocations.

In figure 6, the biomass estimates are given based on the different allocations. For all years, the estimates of total biomass using the alternative allocations overlap with the 95% confidence band of the original estimate. For biomass of maturing capelin, however, there are huge differences in some years due to the length cut-off at 14 cm used to separate maturing capelin from immatures.

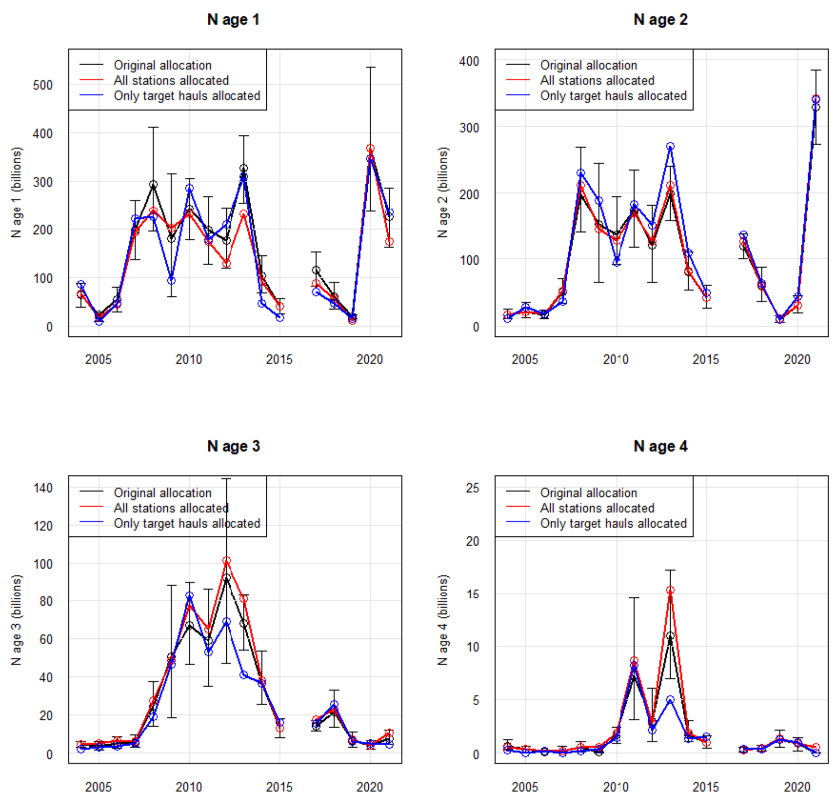

Figure 4. Abundance at age estimated for the age groups 1-4 using the three different approaches for allocation of stations. Arrows mark 5-95% confidence bands for the original estimate.

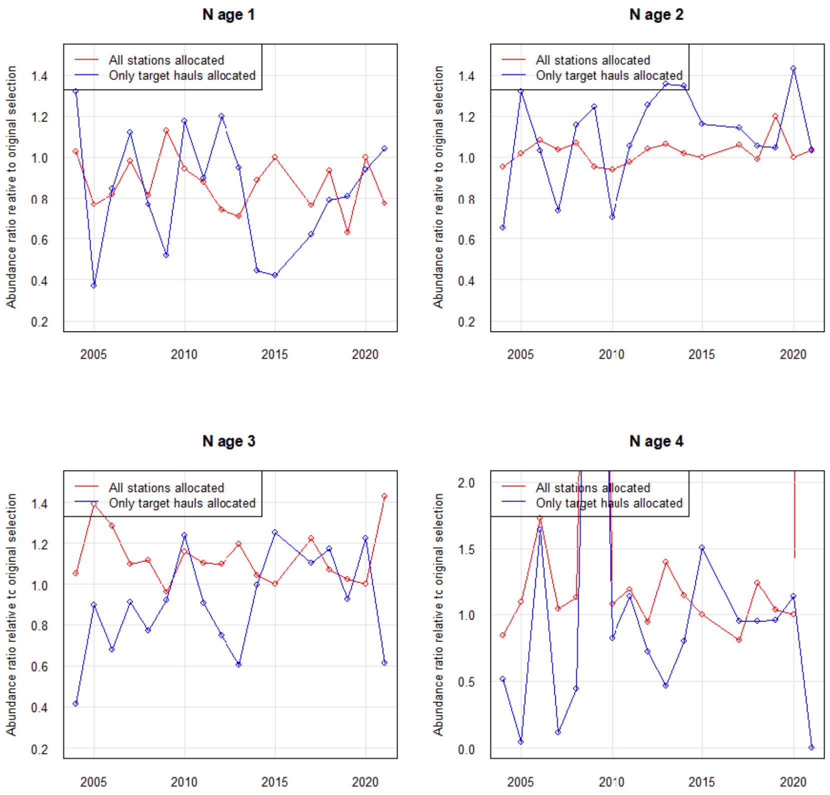

Figure 5. Relative difference in abundance at age between estimates using the two alternative station allocations and estimate based on the original allocation.

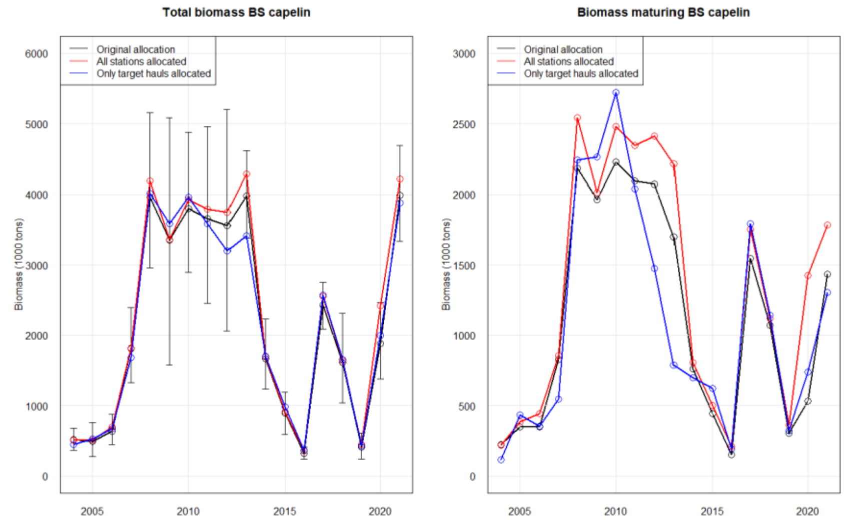

Figure 6. Capelin biomass estimated using the three different alternative station allocations, with total biomass displayed in the left side panel and maturing biomass in the right side panel (assuming a cut-off between immatures and matures at length=14 cm). Arrows mark 5-95% confidence bands for the original estimate.

The results of the evaluation based on internal consistency are shown in Table 1. The estimates based on the original station selection showed the highest correlation both when comparing age groups 1-2 and 2-3. The alternative with only target hauls selected showed highest correlation among the three when comparing age groups 3-4. In most cases the evaluation did not show big differences in consistency between the alternatives and confidence intervals were wide and overlapping (Table 1).

Table 1. Internal consistency (correlation) between the different age groups for the three alternatives of station selection that were tested. The Pearson product moment correlation coefficient is shown with 95% confidence interval in parentheses.

Age groups correlated	Original selection	All stations selected	Only target hauls selected
1-2	0.811 (0.512-0.935)	0.691 (0.276-0.889)	0.808 (0.505-0.934)
2-3	0.903 (0.728-0.968)	0.764 (0.414-0.917)	0.86 (0.62-0.952)
3-4	0.766 (0.417-0.918)	0.796 (0.479-0.929)	0.898 (0.701-0.968)

Suggestion

The evaluation of the station allocation indicates that there are systematic differences in estimates when using the three allocations, and that it matters in particular for the estimation of maturing capelin. Our evaluation based on internal consistency did not provide very clear results, but the consistency was lowest for the allocation using all hauls both when comparing age groups 1-2 and 2-3. The capelin sampled in the demersal trawl are typically not observed on the echogram and are in such cases most likely caught in the acoustic dead-zone (WD_BS1 and WD_BS2). In such cases, they are not representative of the capelin recorded acoustically and lead to over-representation of large capelin (see Figure 2). Somewhat depending on the evaluation of the swept area hauls in WD_BS1 and WD_BS2, we suggest that demersal hauls are not included in the allocation for the acoustic estimate.

Part 2 Estimation of survey CV

Background

In the present assessment of BS capelin, a fixed sampling variance expressed as Coefficient of Variation (CV) of 0.2 for all age groups is used in the input for the maturing stock in the forecast. This was shown to be a 'typical' CV for 2 and 3 year-olds in a study by Tjelmeland (2002). This study also included an estimated uncertainty due to error in the allocation of the acoustic data (scrutiny) in addition to the sampling variance. The uncertainty due to allocation was very low with their assumptions compared to the sampling variance from acoustic and biological sampling. When this work was carried out, there were technical difficulties with estimating annual survey CVs in the short time interval after the monitoring survey was finished before the draft advice had to be ready. With modern computers and the use of Stox, this is no longer a challenge, and CVs by age estimated in Stox have been reported annually since 2016 (JRN-AFWG, 2022). However, these estimates have not been used in the forecast. In the present WD we evaluate CV-estimates for the series 2004-2021 and argue that they should be used in the stock forecast.

Method

Sampling variance is estimated in Stox using a bootstrap routine. For the acoustic trawl estimations we have done here, a baseline model is run N times. For each run biological samples (trawl hauls) are first re-sampled, and then acoustical samples (mean NASC-values at the resolution they are stored, normally 1 nautical mile) are re-sampled. Confidence intervals for different estimators of population parameters can then be estimated. The bootstrap routine was set to run 1000 replicates.

Results

CV by age for all years is shown in Figure 7. The results show that there is a strong year-to-year variability. Moreover, the results indicate that the sampling variance differs between age groups, normally with highest estimates for 3-year-olds which are typically less abundant than the other two age groups. There was a high correlation of sampling variance at age between age groups over the period, indicating that the acoustic sampling and not the biological sampling is the main driver of the variance.

Suggestion

Our results indicate that CV at age vary from year to year likely reflecting different degree of patchiness in the distribution, but also different sampling effort. A fixed CV does not reflect this, and we therefore suggest that annual CV-estimates from Stox are used in the BS capelin stock projection in the future.

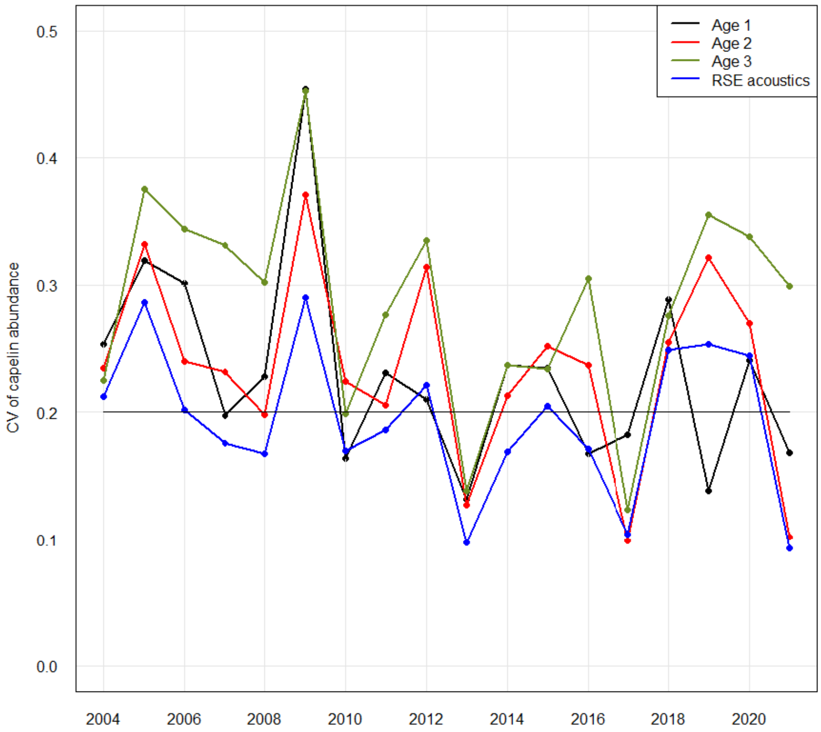

Figure 7. Estimated sampling variance expressed as CV of abundance for capelin based on re-estimation using Stox. The blue line marks estimated Relative Standard Error (RSE) from acoustic data only. This is the estimator described in Jolly and Hampton (1990) based on the variance of mean Nautical Area Scattering Coefficient (NASC; m^2/nmi^2) by transect weighted according to transect length. The black horizontal line marks a CV of 0.2 which is presently used as a fixed value for maturing capelin of all age groups in the stock projection. The estimates are based on 1000 bootstrap replicates.

Work conducted during the benchmark meeting

The sections prior to the present were contained in the original WD presented for the benchmark meeting. The only change made is the addition of the relative standard error (blue line) in Figure 7.

The additions in the following were presented during the meeting on request. Figure 8 shows how CV estimates by year for BS capelin change with abundance for age groups 1-4. Overall, there is a decreasing trend with increasing abundance, as is expected if distribution spreads out and heterogeneity (patchiness) decreases with increasing abundance. When plotting by age groups, the trend is significant for abundance at age 2. A similar, but not significant trend is seen when comparing CV against biomass in Figure 9.

The effect on the forecast of changing the CV by age (while keeping other parameters constant) was tested on various years and the result is shown for two years in Figure 10. For the year 2009 with high estimated survey CV, the catch advice would have changed from 240 000 to 77 000 when applying the estimated CV at age for this year instead of the fixed CV at 0.2. When applying an average CV based on the years 2004-2021, the catch advice would have changed to 200 000 tons. The lower panel in Fig. 10 shows the effect on the forecast of an estimated CV which is lower than the fixed CV at 0.2. Change in catch advice was not calculated in this case.

The sensitivity of the CV estimate to number of bootstrap replicas was addressed during the meeting. We chose the year 2009 which had the highest CV on abundance at age (Fig. 7), and a relatively low number of target hauls (Fig. 1). There was little effect on the estimated CV of age groups 1-3 of increasing number of replicas above 1000 (Fig. 11). For the CV of abundance of 4-year-olds, the estimate did not stabilise with increasing number of replicas up to 10 000. It should be noted that the abundance of 4-year-olds was low.

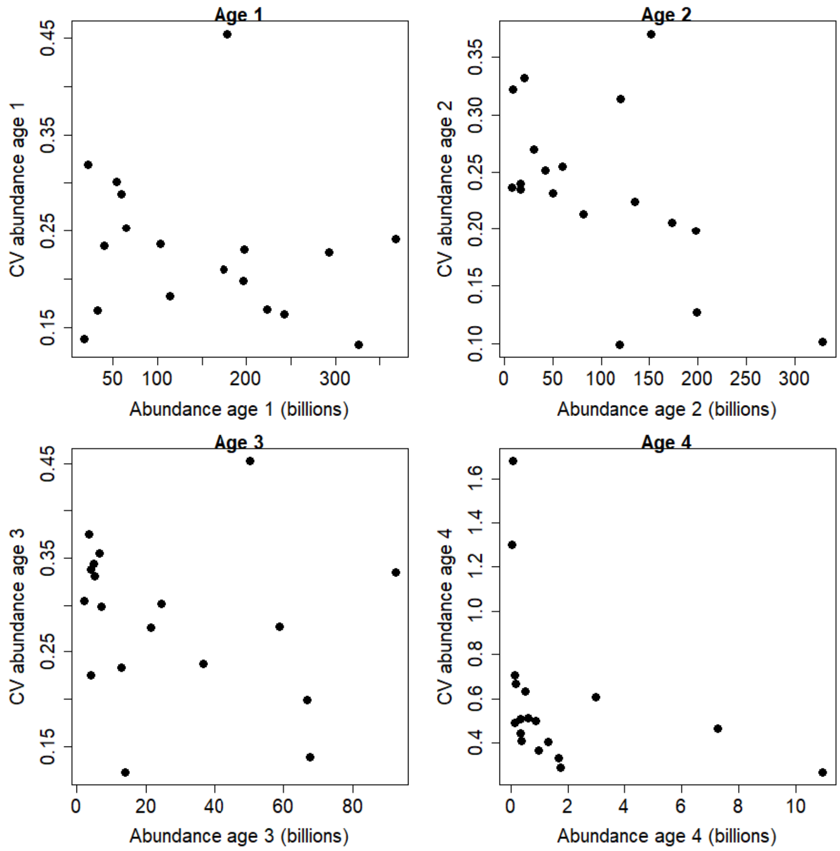

Figure 8. Estimated sampling variance expressed as CV of abundance as a function of abundance at age for the survey years 2004-2021.

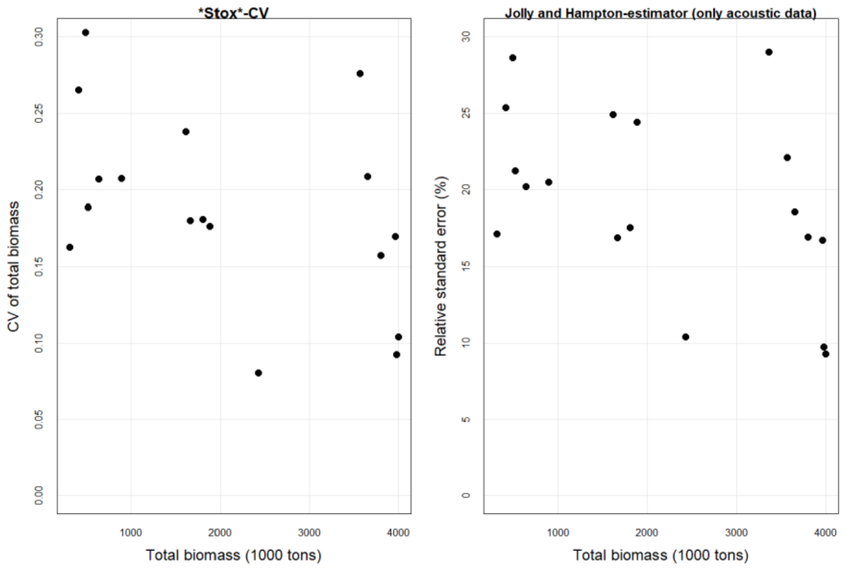

Figure 9. Estimated sampling variance expressed as CV of total biomass as a function total biomass (left) and Relative standard error from only acoustic data (right) for the survey years 2004-2021.

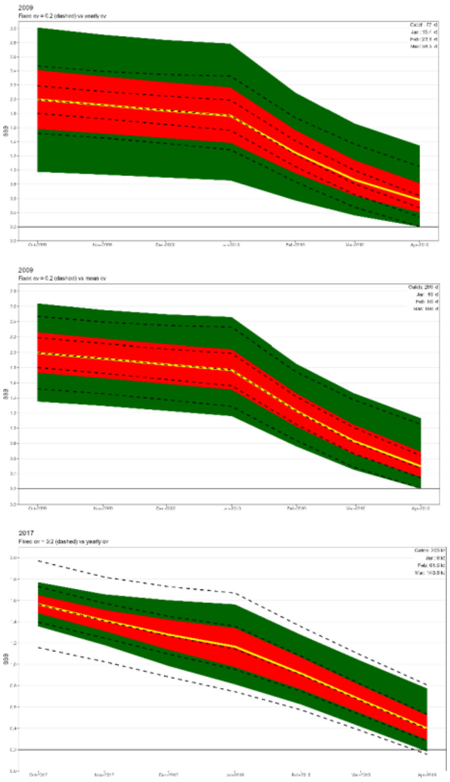

Figure 10. Comparison between original forecast (dashed lines) with a fixed CV on capelin abundance of 0.2 per age group, and forecast using alternative CVs of (upper panel): survey year 2009, CVs estimated from 2009 survey are 0.45, 0.37, 0.45, 1.67 for age groups 1-4, respectively and (middle panel): survey year 2009, average CVs from estimates 2004-2021 are 0.23, 0.23, 0.29, 0.59 for age groups 1-4, respectively. In lower panel the survey year is 2017, and CVs estimated from 2017 survey are 0.18, 0.1, 0.12, and 0.4, respectively.

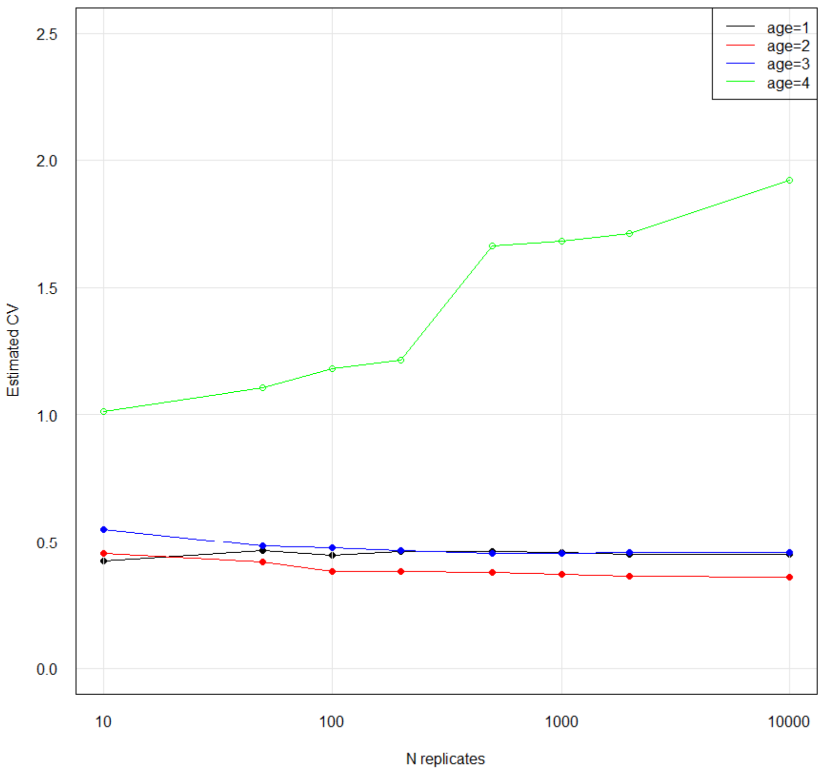

Figure 11. Estimated sampling variance expressed as CV on abundance at age as a function of number of bootstrap replicates in Stox. The results are based on the estimate from the 2009 survey. Note the logarithmic scale on the x-axis.

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Summary of four years of testing trawl-acoustic monitoring of pre-spawning capelin 2019-2022

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Background

In 2018, there was a proposal from the Norwegian fishery industry forwarded through FUR ('Faglig Utvalg for Ressursforskning'; Joint science/industry association for resource investigations), that funding from the Fisheries Resource Tax (FFA) should be spent on a winter monitoring of the Barents Sea capelin spawning migration to evaluate whether such monitoring could be used to improve capelin assessment and quota advice.

The main spawning of the Barents Sea capelin takes place in the period from late February to early April along the coast of northern Norway between Tromsø and Varangerfjord, and also along the Kola coast. If there is opening for a fishery, it takes place on maturing capelin off the spawning areas starting from late January. In the present assessment of the Barents Sea capelin stock, there is only one annual input to assess the biomass, and that is the estimate from the joint Russian/Norwegian Barents Sea monitoring in the autumn (ICES 2020). The quota advice is based on a forward projection of the maturing capelin stock from the autumn survey the previous year to 1st April the present year, including associated uncertainty (Gjøsæter et al. 2002). Previous attempts have shown that monitoring of the capelin spawning migration in the Barents Sea is challenging (Ref: https://www.hi.no/resources/images/3_arig_rapport_gyteinnsig_lodde.pdf), both because the spawning region has a wide geographical extension and because the timing of the migration and hence availability to acoustic detection, is variable. Nevertheless, a reliable winter survey could potentially reduce uncertainty in the assessment of biomass of mature capelin and improve the advice. IMR therefore approved the proposal from the industry and took on to conduct a series of three winter monitoring surveys from 2019 to 2021, which was extended with a fourth year in 2022. The survey results are presented in detail in the survey reports available online for 2019: https://www.hi.no/resources/Toktrapport-loddetokt-mars-2019.pdf, for 2020: https://www.hi.no/hi/publikasjoner/toktrapporter/2020/testing-of-trawl-acoustic-stock-estimation-of-spawning-capelin-2020-nr.-2-2020 for 2021: Survey-report-capelin-spawning-survey-2021_final-1.pdf (hi.no) and for 2022: Testing of trawl-acoustic stock estimation of spawning capelin 2022 | Havforskningsinstituttet (hi.no).

The main objective of this effort was to provide a series of surveys conducted with a timing and a design such that it would have been relevant to use in an advice process if the results are reliable. The results from the surveys can then be applied for an evaluation of the usefulness of such a monitoring for the capelin assessment and advice. Here, we summarize main results and conclusions from the effort.

Methodology

Vessels and timing

In 2019, FV *Vendla* conducted the main survey while FV *Rødholmen* conducted a scouting survey prior to the main survey. In 2020, both *Vendla* and FV *Eros* carried out the main survey with FV *Hovden Viking* as a scouting vessel. In both 2021 and 2022, *Vendla* and *Eros* carried out the survey with no scouting vessel. Survey dates were 4-17 March in 2019 and 26 Feb-12 March in 2020 and 2021 and 27 Feb-13 March in 2022.

Acoustic equipment, data collection and processing

Both Vendla and Eros that have been used for the main survey, are combined trawlers/purse seiners that are equipped to conduct supervised scientific surveying and they routinely conduct resource monitoring of pelagic fish for IMR including surveys on herring, blue whiting, sandeel and mackerel.

Echo sounders

Both *Eros* and *Vendla* are equipped with Simrad EK80 echo sounders collecting data at the frequencies 18, 38, 70, 120, 200 and 333 kHz. Transducers were mounted in a drop keel 3 m below the vessel hull. Echo sounders were calibrated prior to surveying according to standard sphere method (Demer et al. 2015).

Acoustic data collection and processing

Data were collected up to 500 m range and with a ping interval of about 1 second. Raw acoustic data were scrutinized daily using the LSSS software at 38 kHz to the categories 'Capelin', 'Herring', 'Bottom fish', and 'Other'. The scrutinized data were stored at a resolution of 0.1 nmi horizontal and 5 m vertical and exported in units of Nautical Area Scattering Coefficient (NASC; m^2nmi^{-2}). This output was used for the biomass estimation (see section below).

Biological sampling

Harstad trawls were applied on both vessels and rigged according to standard protocol (see survey reports for details on rigging), except in 2022 when Multpelt 832 pelagic trawl were used.

Only target trawl hauls were carried out, i.e. on significant pelagic aggregations that were thought to be capelin. From every trawl haul, a maximum of 100 randomly selected capelin were sampled. Weight and length were measured for all, while age, sex and gonad stage was sampled for 50.

Other data collection

Both Vendla and Eros are equipped with ST90 low frequency (20 kHz) sonars that were calibrated prior the start of the survey following the methodology proposed by Macaulay et al. (2016). Sonar data was collected continuously surveying, and detailed inspection of large schools was done.

Conductivity Temperature Depth (CTD)-data were collected in 2020-2022 spread over the survey area, and a photo rig was deployed for detection of eggs/capelin on the bottom.

The results from the sonar data collection, CTD-casts and video recordings from rigs can be found in the survey reports and are not presented in this summary.

Survey design

We adopted a stratified random transect survey design with the allocation of effort reflecting the expected abundance of capelin within a given stratum. The strata and distribution of effort are shown in fig. 1. It is important to underline that the survey area we have defined is a core area for the capelin spawning migration, and the survey period is adequate in the case an advice would have been provided, but this is not a complete coverage of the Barents Sea capelin spawning stock. In particular, the eastern spawning areas are not covered.

We have implemented a zig-zag transect design, which has the advantage of allowing more time spent on transects and less on transit compared to a design with parallel transects. Like in 2020, we adopted a design including a complementary return zig-zag going in the opposite direction (Harbitz 2019). If the assumption of a stationary population holds, we then get an unbiased abundance estimate by combining the two complementary coverages. In addition, potential population mobility can be examined by comparing the two coverages (Harbitz 2019). An additional advantage is that the effort can be increased in high concentration areas on the second coverage if the first coverage indicates that a different allocation of effort would be valuable. This was done in 2022. In that case the two coverages cannot be combined into one estimate. With two vessels available in 2020-2022 we could use this design in a western area comprising strata 1, 2 and 3 for Vendla and an eastern area comprising strata 4, 5 and 6 for Eros (Fig. 1).

A scouting vessel was used in 2019 and 2020 prior to the main survey. These provided information that was used to allocate survey effort among the strata. In addition, information on recent capelin distribution was available prior to the survey, including information from fish plants reporting the presence of capelin in cod stomachs, data from the ground fish survey with RV Johan Hjort in the Barents Sea (the 'winter survey'), and acoustic and trawl data from the NSS herring spawning survey which finishes just prior to the present survey and overlaps somewhat in the western area coverage.

Strata boundaries were drawn using the software Stox (Johnsen et al. 2019), and allocation of effort within the strata was done using the "survey planner" function in the R package Rstox (https://github.com/arnejohannesholmin/sonR). The method used for generating the zig-zag transect plan was "Rectangular enclosure zigzag sampler" (Harbitz 2019). The starting point of the transects was random in all strata.

Fig. 1. Survey coverage and design in (from upper to lower) 2022, 2021, 2020 and 2019. Fully drawn transects mark tour and dashed transects detour (Only single coverage in 2019). Note that the detour in 2022 was changed to increase sampling effort in a high concentration area.

Biomass estimation

The Stox 2.7 (Stox 3.0.0 in 2021 and Stox 3.3.3 in 2022) application was used to calculate a standard transect-based trawl acoustic abundance and biomass estimate. Some main steps of the protocol can be mentioned: All acoustic recordings outside the transects (due to for instance trawling or sonar inspection) were excluded from the estimation. All transects (from both coverage areas and survey directions) were combined. All the assigned biological stations were given equal weight when generating the total length distribution used in the estimation. Otherwise the protocol steps used for the autumn survey estimate were applied (See WD_BS3). The following target strength – length relationship was applied for the density (numbers/nmi^2) calculation from acoustic data collected at 38 kHz (Dommasnes & Røttingen 1985):

$$TS = 19.1 \log L - 74$$

Abundance of fish in numbers and biomass with associated relative sampling error were estimated by stratum and age based on 500 bootstrapping iterations of biotic stations and acoustic transects.

Results

Echo sounder recordings

The distribution of acoustic backscatter used in the capelin biomass estimation is shown in fig. 2. In all years, capelin has a very patchy distribution. In 2020 and 2021, a few recordings strongly dominate the backscatter. For pelagic fish, when abundance is low, the distribution is typically very patchy with long distance between large aggregations, and there is a low statistical probability of hitting the aggregations. In such situations you expect a high sampling variance (see results from biomass estimation in next section).

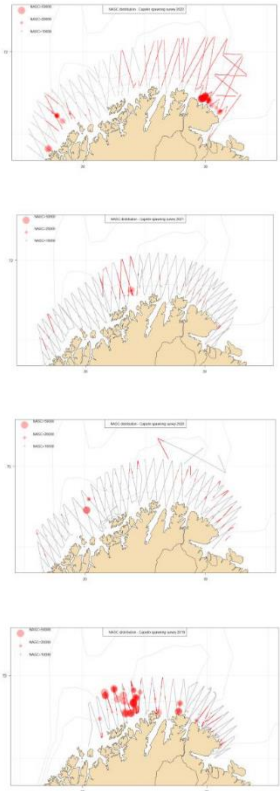

Fig. 2. Distribution of acoustic recordings (Nautical Area Scattering Coefficient; NASC; m^2nmi^{-2}) allocated to capelin and included in the biomass estimation in (from upper to lower) 2022, 2021, 2020 and 2019. The size of the circle corresponds to NASC-value per 0.1 nautical mile, truncated at NASC=50000.

Biology of the capelin

The capelin length distributions for all survey years are shown in Fig. 3. The length distributions from these surveys support the assumption in the stock prediction that capelin >14 cm are migrating to the coast to spawn.

Figure 4 shows capelin maturity stage from the survey for all sampling years. Capelin in maturity stage 5 (late maturing), were dominating in all survey years. The highest proportion of maturity stage 6 (ripe) were found in 2019. The survey was conducted a week later in 2019 than in the other years. A higher proportion of maturity stage 4 was found in 2021 and 2022 than in 2020 indicating that maturity had progressed less even though the timing of the survey was similar. The results indicate that the coverage is early enough to not miss out capelin that have already spawned.

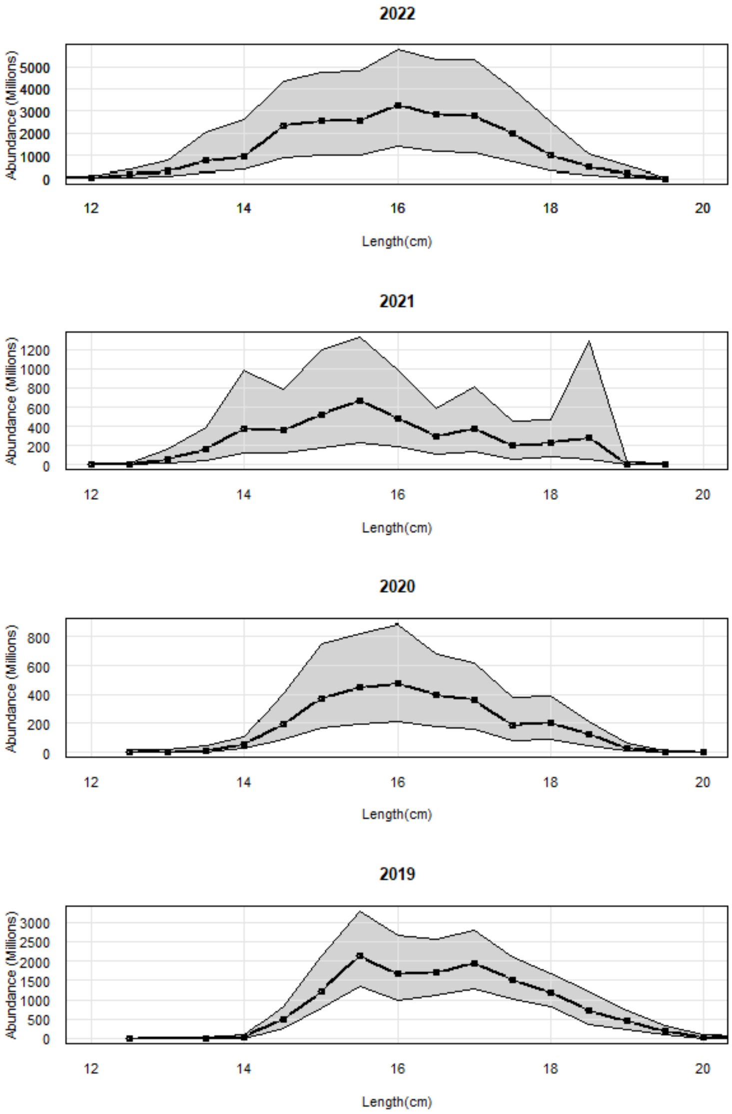

Fig. 3. Length distribution of capelin with 90% confidence interval based on data from the spawning surveys in 2019-2022.

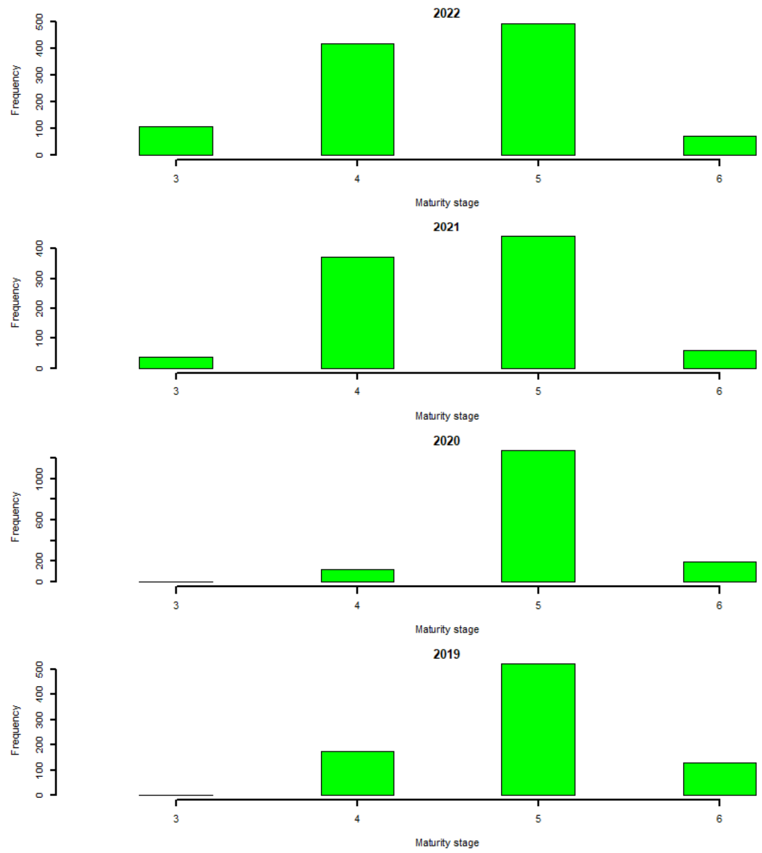

Fig. 4. Capelin maturity stage (3-5: maturing, 6: ripe/spawning, 7: spent) based on the spawning surveys in 2019-2022.

Capelin biomass estimate

An example from the 2021 survey of transects and stations included in the biomass estimation is shown in fig. 5. The biomass estimates from the three survey years with estimates of relative sampling error expressed as Coefficient of Variation (CV) are shown in Table 1. The CV estimates are based on bootstrapping with replacement of transects as well as bootstrapping of biological stations used in the assignment. A 5% lower and 95% upper confidence limit were calculated from 500 bootstrap replicates.

The total biomass estimates were low with high CVs in 2020 and 2021 as was expected from the echo recordings with only very few dense patches (Fig. 2). Also in 2022 capelin were very patchily distributed and the CV is high, even though the estimate of mean biomass is the highest in the series. The biomass estimate from 2019 had lower CV than the three other years. Both for 2020 and 2021, the estimates were higher on the second (eastward) than first (westward) coverage suggesting a dynamic situation.

For all four years, the 90% confidence interval of the estimate is overlapping with the lower range of the confidence interval of the stock forecast (see fig. 6).

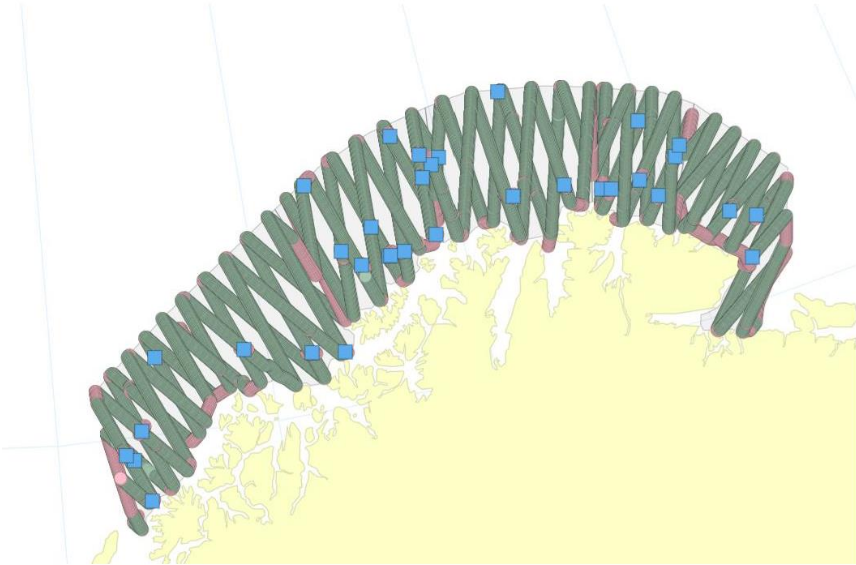

Fig. 5. Overview of transects in the 2021 survey (green: included in the biomass estimation, pink: not included in the biomass estimation). Blue dots mark trawl stations. The gray shaded areas mark the strata (1-6).

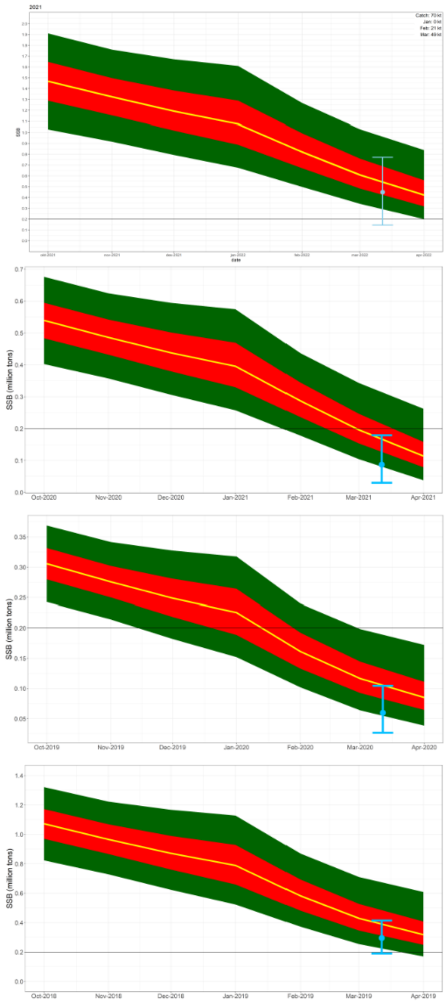

Fig. 6. Modelled projection of maturing capelin stock from 1 October to 1 April for the years 2021-2022, 2020-2021, 2019-2020 and 2018-2019 showing median (yellow), 25/75% quartiles (red) and 5/95% percentiles (green). The blue datapoints with whiskers show median capelin biomass and 5-95% confidence limits from the spawning survey.

Table 1. Biomass estimation (BM, tons), for both coverages (total), eastward (first coverage) and westward (second coverage). Only one coverage was done in 2019, and in 2022 the second coverage was re-designed with higher effort in a hotspot area observed during the first coverage. The total in 2022 is from the second (westward) coverage.

Year	Total (5-95% CI)	CV	Eastward (5-95% CI)	CV	Westward (5-95% CI)	CV
2019	294468 (205342-396945)	0.21				
2020	62298 (26655-104305)	0.38	20579		100350	
2021	88539 (29962-178839)	0.52	27589 (2538-68837)	0.68	153848 (40800-345197)	0.58
2022	426618 (167555-757229)	0.42				

Methodological issues

The capelin abundance estimate is treated as an absolute estimate in the assessment and it is of high importance that the assumptions in the conversion form acoustic recordings to fish density are correct. In particular, changes to the target strength-length relationship have huge impact on the estimate. As part of the efforts with the capelin spawning survey, we have done target strength measurements and investigated frequency response of capelin schools to investigate whether they follow the expected pattern of fish with swimbladder. The investigations are described in detail in the Appendix, but to summarize the results the frequency response of capelin schools in some cases show a very surprising pattern more like mackerel response (fish without swimbladder) than typical capelin response. The results show that the frequency of this feature varies among areas and among years. The TS of single fish from such schools is very low at 38 kHz, much lower than expected from the standard target strength-length relationship applied for capelin.

Evaluation of the capelin spawning survey after four years

1. The applied vessels and design provide efficient monitoring of maturing capelin that is approaching the coast at the time of the survey, and overall bad weather conditions have not significantly influenced the acoustic or biological sampling.

2. For all four years, the survey results overlap with the lower range of the confidence band of the stock forecast based on the autumn survey. It is expected that the results are in the low range given the lack of coverage in the east, and the consistency in results despite the dynamics of the migration is promising for the use of such monitoring for advice purposes.

3. The results from the acoustic recordings underline that there is significant dynamics in distribution during the survey period as can be expected.

4. In two out of four survey years (2020 and 2021) both expected and measured spawning biomass have been low which is not ideal for testing the survey. The high CVs despite the good coverage for these years reflect a very patchy distribution with only a few very high acoustic recordings. Also in 2022, the distribution was very concentrated despite a significantly higher spawning biomass than in 2020 and 2021. A semi-adaptive design with either adjustment of effort in a second coverage or the use of a scouting vessel seems appropriate for addressing high patchiness.

5. Multi-frequency recordings and TS measurements revealed unusual backscattering properties of the capelin which potentially can have significant impact on the abundance estimate. This must be taken into account in the case where the results from the survey are used for capelin quota advice.

Example of the use of a spawning survey in the advice process

The idea with a spawning survey is that it can be used for updating the advice from the autumn along the lines of how it is done on the IEGJM capelin stock (ICES, 2022). A generic example is shown in Fig. 7. The example is not based on real data, but illustrates how a forecast from an initial spawning biomass of ca. 2 million tons is updated after the pre-spawning survey. A new forecast is run after the end of the pre-spawning survey and catch advice is updated accordingly.

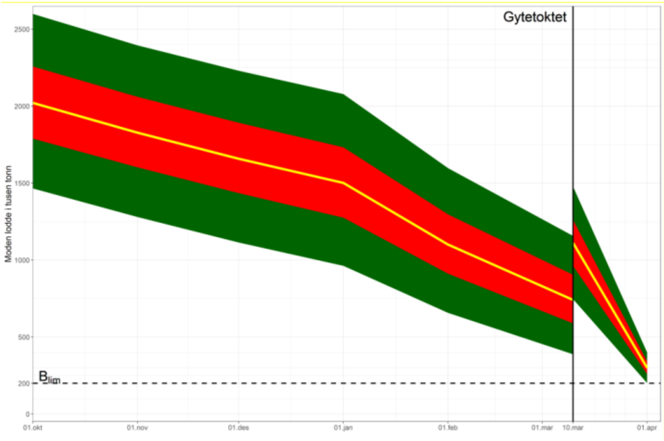

Fig. 7. Illustration of how the pre-spawning survey is used to update the stock forecast which is originally based on the autumn survey. The illustration is not built on real survey results, but shows median biomass of maturing capelin in yellow, 25/75% quartiles in red and 5/95% percentiles in green. The vertical line marks the end of the pre-spawning survey.

Appendix

In this Appendix we provide a short background and description of methodology and preliminary results for capelin acoustic target strength investigations and acoustic frequency response. Such studies have been in focus during the pre-spawning surveys. Note that the text here are largely taken from the survey reports, and only slightly modified. There is ongoing work on these topics and the results will be presented in the proceedings from the 2022 ICES symposium on capelin.

Acoustic target strength investigations

TS measurements – Background

Fish target strength (TS) is a key parameter for abundance and biomass estimation of fish stocks when using the acoustic echo integration method. The target strength represents the acoustic backscattered energy from a single fish and is used to convert the echo energy measured with an echo sounder into number of fish. The conversion is normally done through a target strength-length relationship which for Barents Sea capelin is defined as TS= 19.1 log(L)-74 at 38 kHz. This relationship is derived from ex-situ measurements of maximum TS of capelin and other species (Dalen et al., 1976) and theoretical corrections to convert it into a mean TS relation (Dommasnes and Røttingen, 1985). *In situ* target strength measurements that reflect the acoustic backscattering of free-swimming capelin are needed, in particular when there are new survey situations like the spawning survey represents.

Measurements of single fish are required for deriving reliable estimates of TS. That is a challenge in schooling species like capelin, especially during normal acoustic surveying. However, deployment of an echo sounder close to the fish targets and the use of broadband echo sounders will increase the chances of obtaining measurements of single individuals. In the 2021 capelin spawning survey we used submersible independent transducers for the TS measurements, and in 2022 survey Target Strength probes (TS probe) were made available both for *Eros* and *Vendla*.

Data collection

Following from the experience gained in 2020 and 2021, a dedicated TS probe was used to carry out TS measurements of capelin. In order to detect single fish close to or inside a capelin school it is required to have: high ping rate, a narrow beam and broadband transmission mode. The TS probes used on board Vendla and Eros were equipped with 4 Simrad wideband transceivers (WBT) operating at frequencies of 38, 70, 120 and 200 kHz. All transducers are depth rated and have full broadband transmission on all frequencies except for the ES38D, which has a limited broadband (34 to 42 kHz). The settings used for calibration and data collection are shown in Tabs 4a and 4b. The echosounder systems are mounted in a rigid frame that can be lowered to the desired depth and controlled and monitored in real time via fiber optic to the vessel (Fig. A1). The frame was submerged as close as possible to the capelin school which had been detected with the vessel echo sounder. To avoid acoustic interference with the TS probe echo sounders, the vessel echo sounders were stopped during deployment of the probe. Once the probe reached the desired depth, the vessel was slowly maneuvered aiming to stay on top and at the borders of the school during the measurements, by using the sonar during brief periods.

Fig. A1. Retrieval of the TS probe onboard Eros after data collection for single fish target strength measurements.

Table A1a) Setting used for calibration and collection of acoustic Target Strength (TS) data with the TS-probe on board Vendla.

Channel	Pulse shape	Bandwidth, kHz	Taper	Pulse duration, ms	Power, W
38-CW	CW	-	-	0.256	200
38-CW	CW	-	-	1.024	200
38-FM	FM-Up	34-42	Fast	2.048	200

Table A1b) Settings used for calibration and collection of acoustic Target Strength (TS) data with the TS-probe on board Eros.

Channel	Pulse shape	Bandwidth, kHz	Taper	Pulse duration, ms	Power, W
38-CW	CW	-	-	1.024	200
38-CW	CW	-	-	0.256	200
70-FM	FM-Up	55-85	Fast	2.048	75
120-FM	FM-Up	95-165	Fast	2.048	80
200-FM	FM-Up	170-260	Fast	2.048	105

The TS probe onboard Vendla malfunctioned when several frequencies were run simultaneously or when the tilt and roll system was run, so only the 38 kHz transducer was calibrated.

During deployment, data were collected with single band (CW) and broadband (FM). A pelagic trawl was carried out for biological sampling of the capelin either before or after the deployment.

After the deployment data were examined in the EK80 software, and detailed analysis of single targets will be done at a later stage.

Results

Five TS probe deployments were done on Vendla and two on Eros. Single target measurements were possible when the fish was dispersed enough to be isolated as single individuals (Fig. A2). When fish was found in densely packed schools, it was difficult to resolve single fish even with the probe very close to the school. In Fig. A2 single fish detections are shown as black dots and it is possible to identify continuous lines of dots representing tracks of single fish.

Preliminary results indicate target strength values in the level expected when using the standard TS length relation (TS=19.1 log(L)-74), which corresponds to a TS of -51 dB assuming a fish mean length of 16 cm. These results agree with a general impression that the frequency response of most of the capelin aggregations (in particular the large ones in the eastern region) showed an expected decrease in echo strength from lower to higher frequencies, typical of a fish with a filled swimbladder.

A more detailed analysis of the TS probe deployments will be done following procedures used in previous years, filtering the data by range from the transducer and cut-off angle to ensure normal target distribution inside the acoustic beam. In addition, tracking algorithms will be used to identify single fish and calculate corresponding track target strength. This method reduces the chances of obtaining target strength from multiple targets.

The use of the TS-probe was logistically more challenging than the use of a single frequency submersible transducer that was used last year. However, the use of the TS-probe provided the flexibility to lower the transducer to any depth close to the fish and provided the option to run multifrequency transducers with broadband capabilities.

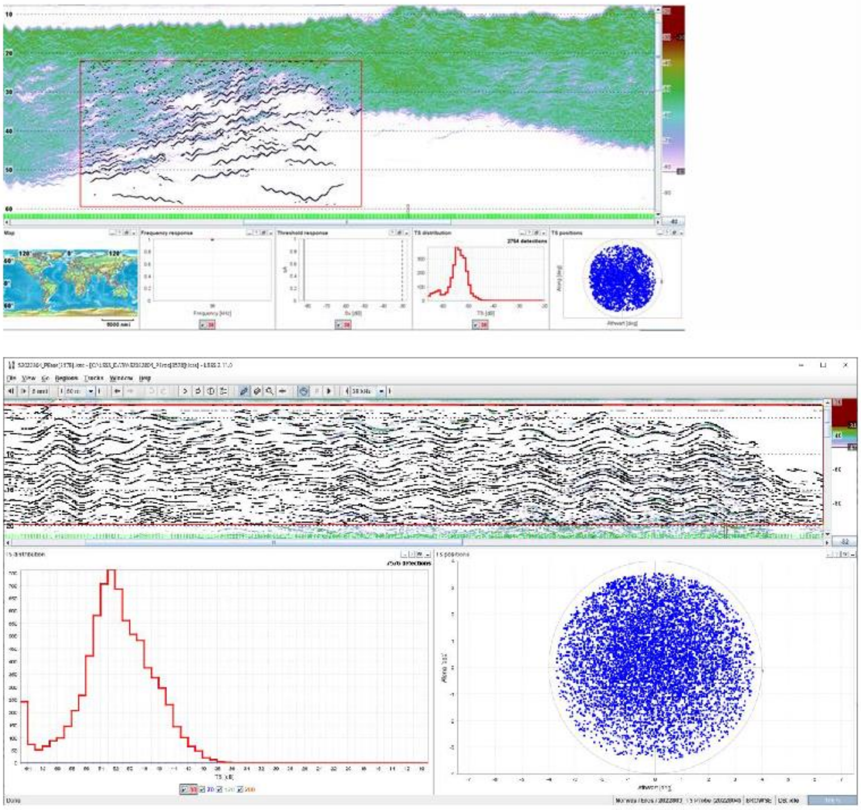

Fig. A2. Echograms showing TS probe measurements at 38 kHz in CW transmission mode from Vendla (upper panel) and Eros (lower panel). Single individual fish were detected below a denser layer in the data from Vendla , and from a very disperse layer in Eros data. The histogram shows the target strength of the single targets and the polar plot their position inside the beam.

Capelin acoustic frequency response

Introduction

Capelin has a physostomous swimbladder, with a connection to the esophagus, with no capacity to secrete gas (Fahlén, 1968). The swimbladder is typically contributing 90-95% of the backscatter from fish that poses one (Foote, 1980). Swimbladder fish display a characteristic frequency response in the frequency range used in fisheries acoustics (i.e. from 18 to 200 kHz), with strong backscattering at lower frequencies decreasing toward higher frequencies. Fish without swimbladder, like Atlantic mackerel, have stronger backscattering at higher frequencies decreasing at lower frequencies (Korneliussen, 2010). In the case of fish without swimbladder, the fish flesh and bone structures contribute most to the backscattering.

Normally, Barents Sea capelin is monitored during the autumn and display the classic frequency response of swimbladder fish. In this capelin spawning survey, we monitor capelin in a completely different state and situation, which potentially influences physiology and backscatter properties at various frequencies. Here we present some examples of the frequency response of capelin schools recorded during the 2021 survey, aiming to show the variability observed, and discuss potential implication on the survey results.

Methods

Multifrequency data was obtained from the EK80 calibrated systems onboard "Eros" and "Vendla", from 18 to 200 kHz. Schools along and outside the track line were sampled with the echo sounder, at survey speed (10 knots) or reduced speed for inspection or trawling. Capelin is reported to have little or no reaction to an approaching vessel (Jørgensen et al., 2004), making sampling with echo sounder a reliable measure of its acoustical properties.

Echo sounder data from various capelin aggregations (schools and layers) observed during the survey was inspected in the LSSS software and the frequency response was obtained.

Results

Echograms showing an example of a capelin aggregation with abnormal frequency response is shown in Figure A3. There is highest backscattering at 200 kHz, and backscattering is decreasing at lower frequencies. The strength of the backscattering at 200 kHz in the example is ca. 5 times higher than at 38 kHz.

The depth of the capelin schools with abnormal frequency response varied from close to the surface to 200 m depth. The time of the day also varied, as well as school size. Predators (whales, dolphins and large demersal fish) were observed in various abundances around all schools, both visually and in the acoustic data (echo sounder and sonar).

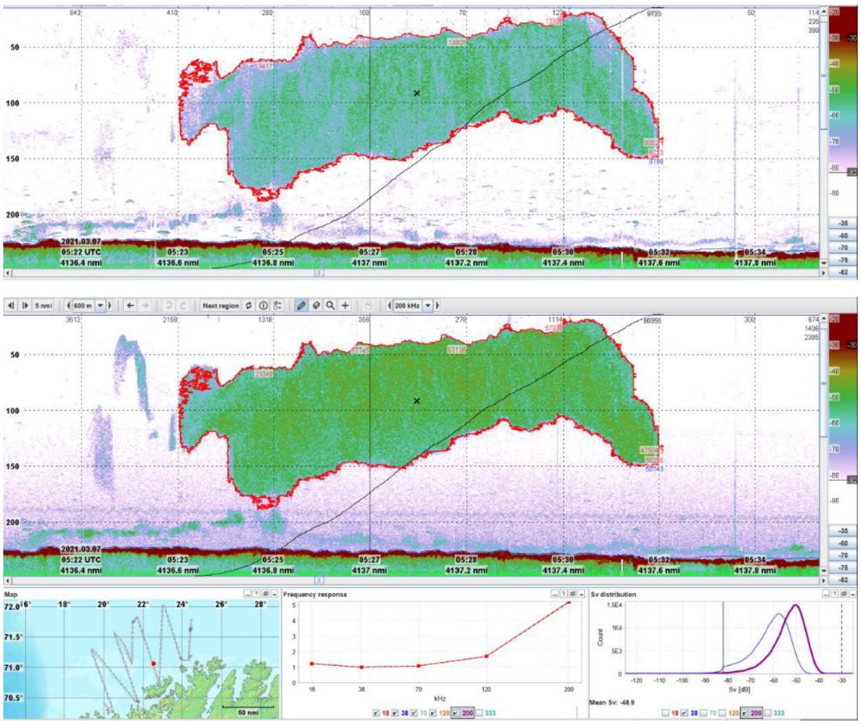

Fig. A3. Echogram example from "Vendla" with a big school of capelin and gadoid aggregations below recorded at 5:30 UTC north of Sørøya. The recordings are done at 7-8 knots speed. The upper panel displays the 38 kHz echogram showing the frequency response of the school delineated by the red line, and the lower panel the 200 kHz echogram. Frequency response from 18 to 200 kHz is displayed in the bottom center panel.

Discussion

The abnormal frequency response observed in capelin schools during the 2021 survey has previously been registered occasionally, but not quantified or investigated further.

We assume that the unexpected frequency response is due to the fish emptying or partly emptying the swimbladder under certain circumstances, which has also been observed in herring (Nøttestad et al. 1998). The resulting low backscattering at 38 kHz will have significant implications on the abundance estimation of capelin in such schools, since the conversion from acoustic backscatter to number of fish is assuming that fish have gas filled swimbladder (TS=19.1Log(L)-74). The target strength of a fish with empty swimbladder will be much lower, and a different formula for conversion should be used for such schools.

Possibly the measured schools had emptied their swimbladder in response to predators, escaping vertically and releasing air and/or as a precautionary anti-predator strategy to reduce the risk of being detected by predators, in particular by marine mammals which use acoustics to localize their prey. The characteristics of the capelin swimbladder, with an opening to the esophagus support these hypotheses. In 2020, some schools attacked by demersal fish were observed acoustically to seemingly release gas (Fig. A4).

It will be important to quantify the extent of abnormal frequency response as a part of the evaluation of this survey time series.

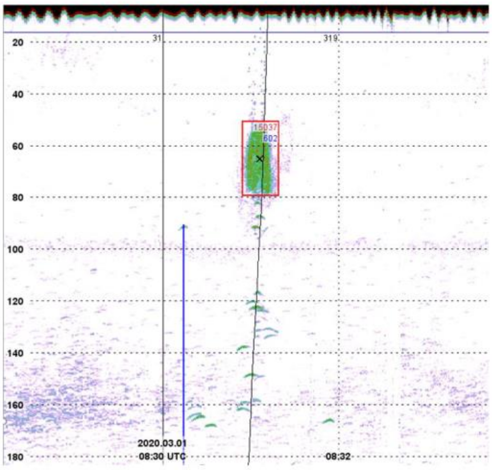

Fig. A4. Echogram showing a capelin school (delimited inside a red region) releasing gas, as green dots above the school all the way to the surface. Below the school it is possible to identify large demersal fish (as green arch shapes), most likely cod, attacking the school from deeper waters.

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Predation by cod on capelin in the Barents Sea and calculation of capelin consumption by cod.

WD_BS5, WKCAPELIN, 21-25 November 2022

Updated 12 December 2022

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Introduction

Capelin is the most important food item for cod in the Barents Sea, especially in winter, and cod is the most important predator on capelin (Holt et al. 2019, Bogstad et al. 2000). Thus, consumption by cod has been included in capelin assessment since the early 1990s (Gjøsæter et al. 2002; 2015).

Key issues related to the assumptions in the assessment consumption model are:

- Which part of the cod stock prey on capelin during capelin spawning migration (January-March or shorter period)?
- Do the cod then prey only on maturing capelin?
- How much capelin is eaten by each cod, and how is this dependent on abundance of capelin and possibly of other food?

Cod is of course also preying on capelin during October-December, but this is not explicitly modeled. Instead we use a survey-based mortality for this period (see WD_BS6). The actual data used in the prediction model are given in WD_BS7.

Available data

- Total abundance of cod
- Spatial distribution of cod in winter
- Stomach content data from joint Norwegian-Russian stomach content data base (1984-present, on average ~9000 cod stomachs sampled annually)
- Stomach evacuation rate model (dos Santos and Jobling 1995)

Abundance of cod overlapping with capelin

The total number, weight and proportion mature cod at age on 1 January each year is taken from the most recent stock assessment (Anon. 2022). In the existing capelin assessment model, it is assumed that only immature cod prey on capelin in January-March. Predation by mature cod on maturing capelin in January-March may not be negligible, even though the spawning migration patterns of both stocks generally indicate low overlap during this period. This issue was not investigated further during WKCAPELIN. Further, the assumptions made about predation by cod at age 1 and 2 on maturing capelin are unchanged, i.e. the predation by age 1 cod is zero and by age 2 cod is much lower than for older cod – the suitability factor by age is set to 0.1 compared to 1 for all older age groups (i.e. 10% of age 2 cod are able to prey on capelin). The reason for this is that age 1 and most of age 2 cod are not large enough to prey on maturing capelin, as shown in the predator size/prey size plots in Holt et al. (2019).

Like it has been implemented previously, we still assume that a part of the immature cod stock is found in the Svalbard area where it does not overlap with maturing capelin, as the abundance of maturing capelin found to the west of Svalbard is usually very low. However, the proportion of immature cod in the Svalbard area has been recalculated for the present model. Swept area index based on demersal trawl hauls in the winter survey is used for the recalculations. Since 2014, the winter survey has covered area N, strata 24-26 (blue in Fig. 1), and the proportion of cod in these strata is now used to define the Svalbard component of the cod for 2014-2022. For the years prior to 2014, the average proportion for the period 2014-2022 is used. Fig. 1 also illustrates the annual variability in spatial distribution of cod during winter.

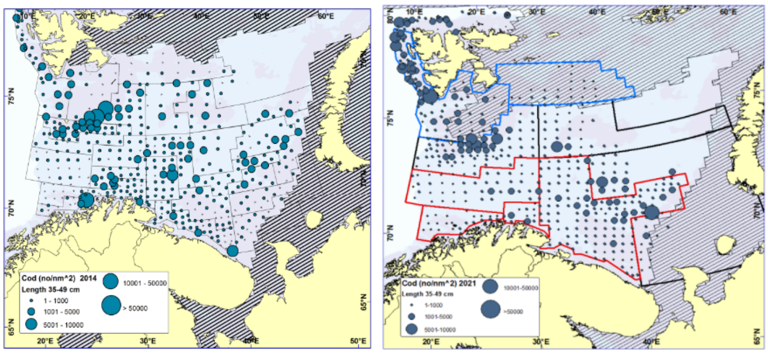

Fig. 1. Spatial distribution of cod based on swept area indexes from bottom trawl during the winter survey 2014 and 2021, for length group 35-49 cm.

Stomach data and consumption calculations

Cod stomachs are sampled at sea, most of them are then frozen and analyzed in laboratory, all are analyzed individually. Weight and length distribution of prey is recorded – but in many cases prey can only be partially identified. A notable proportion of stomach content is identified as Teleostei (bony fish) or totally unidentifiable and this needs to be accounted for in the calculations of consumption. Also, only about 20% of capelin biomass in cod stomachs is length measured. In the calculations described below, prey identified as fish or totally unidentifiable is redistributed using identified prey (species and length distributions) as distribution keys, under the assumption that this does not create any bias.

To calculate consumption, an evacuation rate model (which includes temperature) is needed in addition to stomach content data. We use the model by dos Santos and Jobling (1995). For our model runs and parameter estimations, we decided to use the annual calculations of food consumption by cod (Bogstad and Mehl 1997, updated calculations shown in ICES 2021) as a basis. In these calculations, consumption by cod of various prey species and prey size groups is calculated for each half-year, cod age group and area in the Barents Sea (west, east, north). The spatial distribution of cod is based on annual survey data.

The stomach data for the first half of the year are dominated by data from the annual winter survey in January-March, but also data from other surveys as well as samples from Russian commercial vessels are included. For a given area/time period/cod age group combination, no weighting of data is applied. Using these data to calculate monthly consumption in the first three months (half-year consumption divided by 2) seems reasonable, although it could be argued that they should only be used to model consumption for the months February and March. The stomach content data base certainly allows for redoing the calculations based on only data from the winter survey, but this was not done for the meeting as software for extracting the data on cod age groups and taking into account both partly determined stomach content and linking to actual temperature at the station in question was not available. The trends in consumption per cod from the consumption calculations and from the Partial Fullness Index (PFI) are very similar, as shown in Fig. 2.

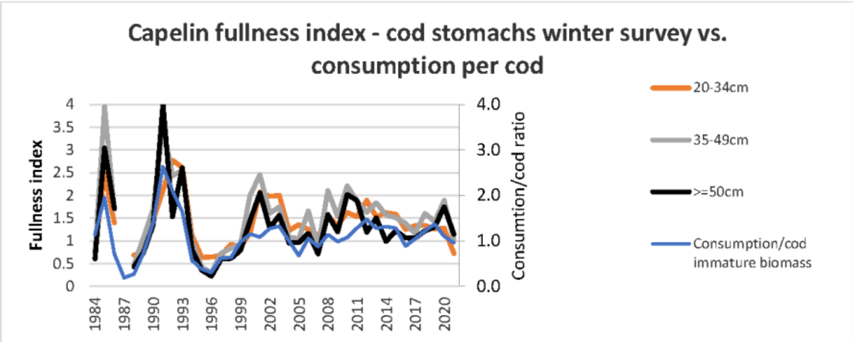

Fig. 2. Capelin fullness index based on the winter survey vs. capelin consumption per cod biomass

Stomach content data – exploration

Some data exploration was done which proved very useful for checking model assumptions. We looked at both size distribution of capelin in cod stomachs as well as temporal and spatial differences of capelin abundance in cod stomachs. Figs 3-5 show the proportion of immature (< 14cm) and maturing (14 cm and above) capelin in cod stomachs, measured as PFI= (100*SW/BW) where SW is stomach content weight of the actual prey category and BW is cod body weight. This was calculated by aggregating data for cod age groups 3-7, which are the main cod age groups preying on capelin during this period. The years before 1993 are not shown in the plot as capelin lengths were then recorded on a coarser length scale (5 cm groups, e.g. 10-14 and 15-19 cm) and can thus not be used to split the capelin found in cod stomachs on size groups above or below 14 cm. The data was divided spatial and temporally into three area/time categories: 1) Svalbard area (in this case survey areas N+S, see fig 1. where S is the westernmost area between the red and blue lines), 2) the rest of the Barents Sea during first half of the winter survey (before 15 February) and 3) the rest of the Barents Sea during the second half of the winter survey (15 February and later).

Figs 3 and 4 show the capelin PFI for the three time/area categories, and Fig. 5 shows the proportion of capelin PFI which is immature capelin.

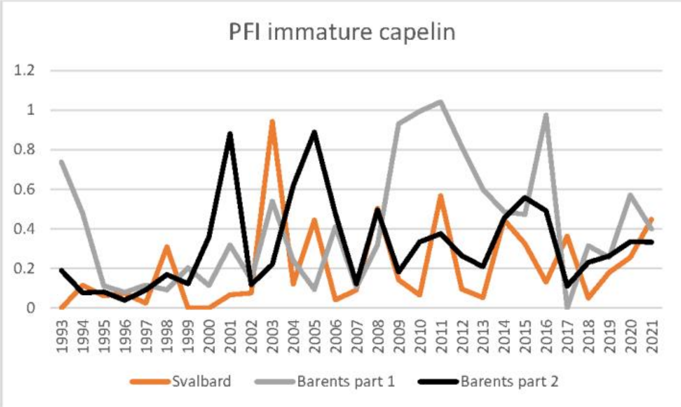

Fig. 3. PFI of immature capelin during the winter survey, for the Svalbard area and Barents Sea (part 1 before 15 February and part 2 from 15 February onwards).

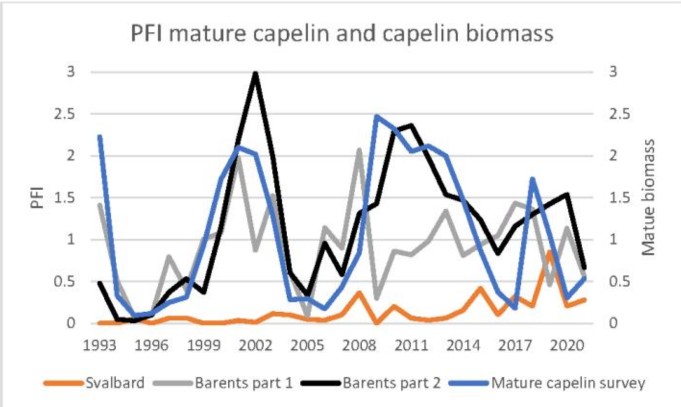

Fig. 4. PFI of maturing capelin during the winter survey, for the Svalbard area and Barents Sea (part 1 before 15 February and part 2 from 15 February onwards).

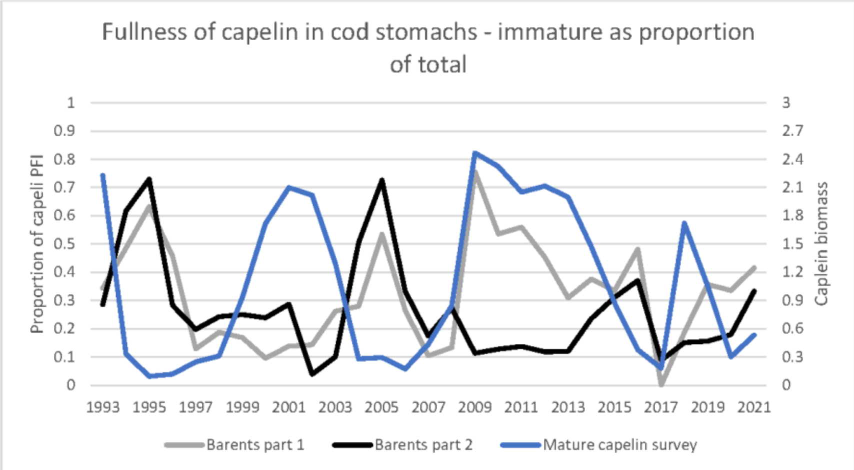

Fig. 5 Proportion of capelin PFI which consists of immature capelin (< 14cm), compared to survey abundance of maturing capelin the previous autumn.

We see that the proportion of capelin in cod stomachs in the Svalbard area is much lower than in the Barents Sea, except in some recent years (Fig. 3). Also, the capelin PFI in the period from 15 February onwards is generally higher than in the first period and varies similarly to the mature capelin abundance (R^2=0.49) as shown in Fig. 4. Based on Fig. 5 it was decided to calculate the annual proportion of the capelin consumed which is immature and account for that in the model (see BS7).

It should be noted that the area closest to the Norwegian coast, where the capelin spawning grounds are found, are always covered during the second part of the winter survey, i.e. after 15 February, so the difference in capelin PFI between the two periods is also related to spatial variation and not only to the time period. Fig. 6 shows spatial distribution of stomach fullness in a high capelin year (2014).

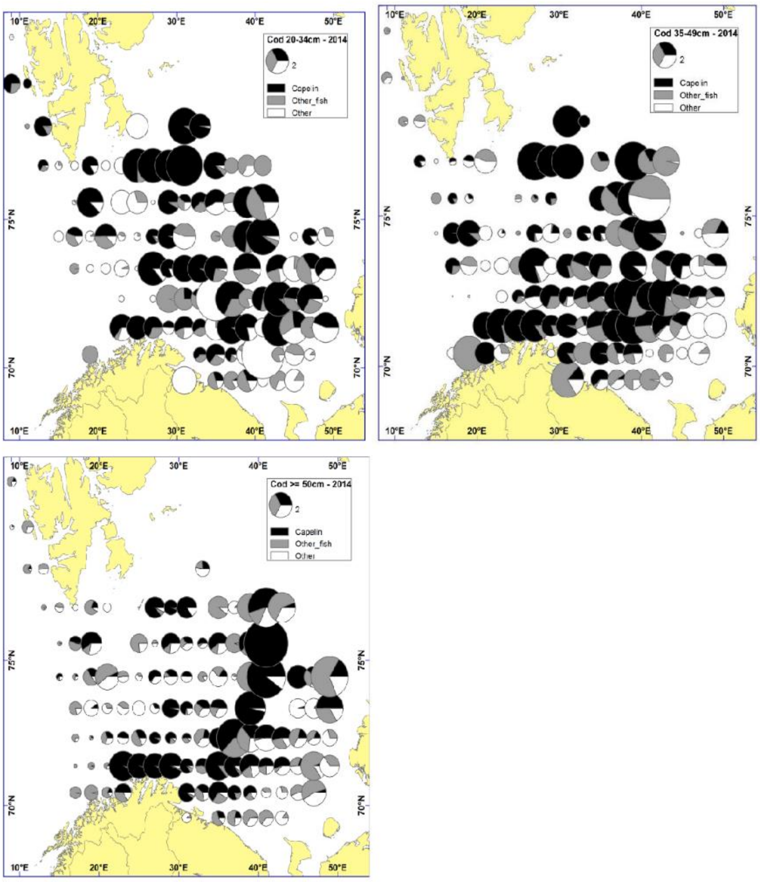

Fig. 6. Spatial distribution of stomach content of capelin from the winter survey 2014, by 1° x 2° areas, for length groups 20-34 cm, 35-49 cm and 50cm and above.

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WD_BS6 Revision of basis for the mortality used in the autumn stock forecast

Georg Skaret, Bjarte Bogstad and Sondre Hølleland

Background

In the assessment of the Barents Sea capelin, there is an autumn forecast of the maturing part of the stock – in the present implementation going from 1 October to 1 January. Survey mortality is used to estimate natural mortality in the autumn and in the current implementation the mortality is estimated year by year together with maturation parameters in a stepwise process described in Tjelmeland and Bogstad (1993). Replicates from the estimation are used in the practical assessment for the annual autumn forecast. In recent years mortality values from the years 1980-1985, 1990-1993 and 1997-2002 have been selected and used. In each simulation run, a value from one of these years is randomly picked.

Suggestion for update

Survey mortalities from age 1 to age 2 and from age 2 to age 3 are plotted by survey year in Fig. 1. We suggest to use survey mortality from age 2 to age 3 as basis for the autumn mortality for maturing capelin in the forecast. We consider the mortality from age 2 to age 3 to be more representative of mortality for maturing capelin than mortality from age 1 to age 2. The younger capelin component has a different distribution both horizontally and vertically and likely experience different predation pressure than older capelin (Gjøsæter, 1998; Berg et al., 2021).

We propose to remove two years from the estimation of the autumn mortality due to sampling issues. This considers mortality values which are affected by the survey year 2016 (cohorts 2013 and 2014 for mortality from age 2 to age 3; table 1). 2016 is an outlier in the time series, but the reason(s) for this is not clear. Possible survey issues are described in Skaret et al. (2016). Average annual survey mortality from age 2 to age 3 after removing these two years is **0.93**.

There are several years with low abundance of capelin measured at age 2 (Fig. 2). For these years, there is a high variability in survey mortality including negative survey mortalities in some years which must be due to sampling error. If we remove these low years by introducing a cut-off at N=60 billion 2-year-olds, average annual survey mortality is **1.01**. In Fig. 3 the abundance of these selected cohorts are plotted at age 3 in year y+1 as a function of immatures age 2 in year y. Annual survey mortality based on the regression through these points is **0.77**.

Issues to decide on:

1: Which M values to use in estimation of predation parameters (annual or fixed)?

2: Which time period(s) to draw M values from for future estimations. We need a method for this – either criteria for selecting relevant years (capelin abundance, cod abundance etc.) or a regression approach.

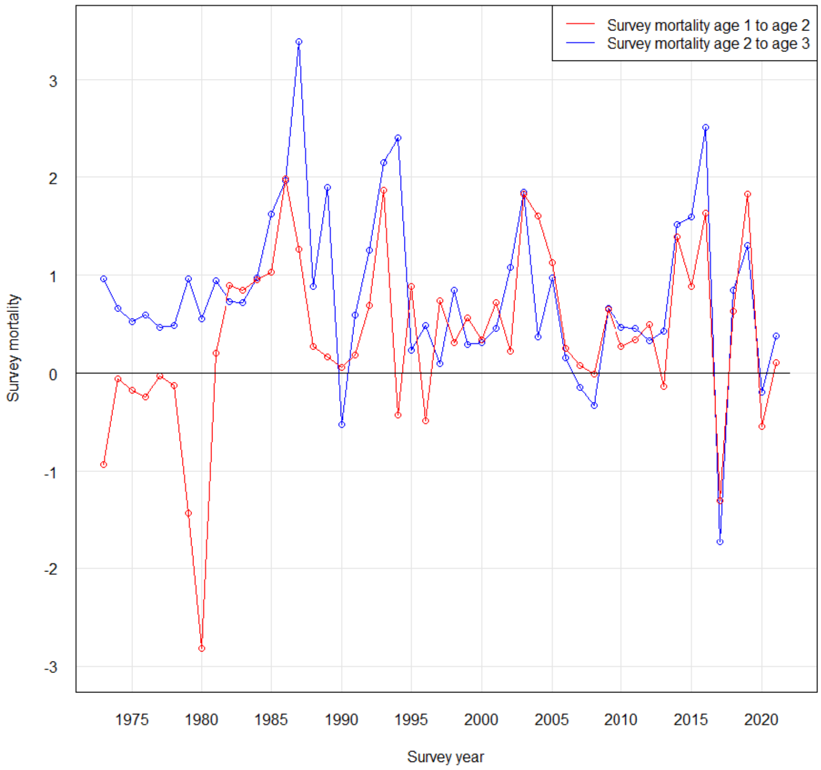

Fig. 1) Survey mortality by survey year. Survey mortality is calculated as -log((N age a+1 in year y+1 + catch immatures in year y and year y+1)/N imm age a in year y). Capelin >14 cm are assumed to be maturing.

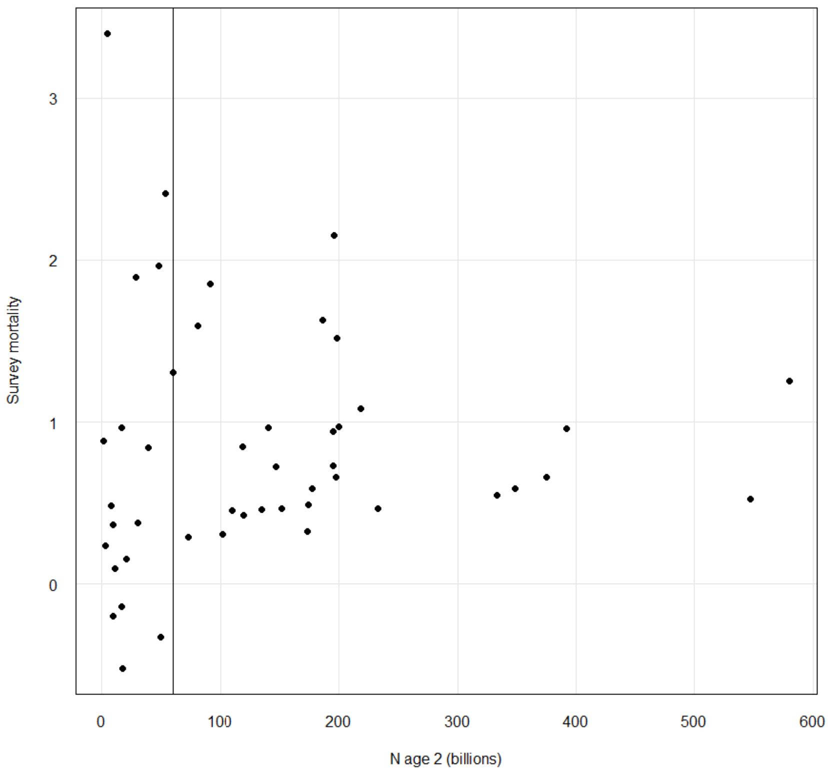

Fig. 2) BS capelin survey mortality from age 2 (immatures) to age 3 as a function of abundance at age 2. The vertical line indicates a cut-off at N=60 billion 2-year-olds above which the variability in estimated survey mortality is lower and with no negative values. Survey mortalities for cohorts 2013 and 2014 have been removed (see text).

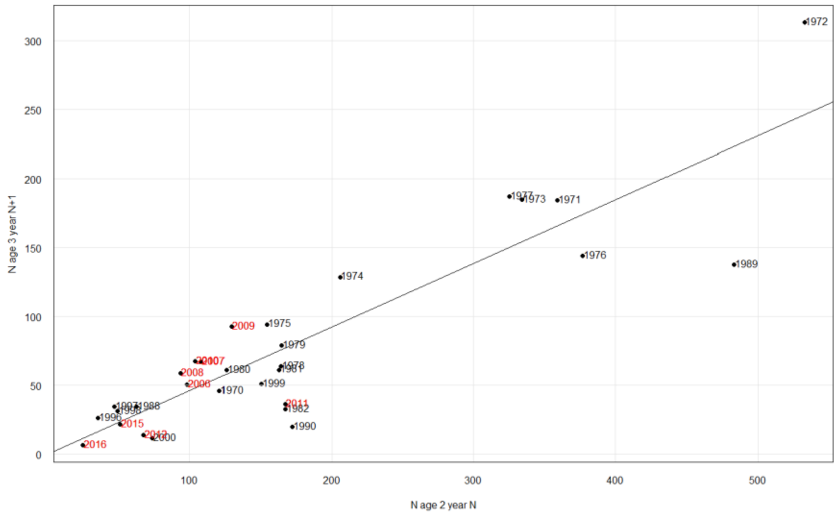

Fig. 3) N at age 3 in year y+1 as a function of N immatures at age 2 in year y. Cohorts with abundance <60 billions at age 2 (when combining maturing and immatures) have been removed (see fig. 2), and catch on immatures is added to the abundance of 3-year-olds. The regression is forced through origin. Cohorts from years with the ecosystem survey are marked in red. Annual survey mortality based on this model and these data is 0.77.

Table 1. Capelin survey mortality from age 2 (immatures) to age 3 by cohort. Z is calculated as -log(N age 3 in year y+1/N imm age 2 in year y). M is calculated as -log((N age 3 in year y+1 + catch immatures age 3 in year y+1 and age 2 in year y)/N imm age 2 in year y). Capelin >14 cm are assumed to be maturing. The cohorts affected by the outlier survey year 2016 are marked with red.

Cohort	N imm age 2	N mat age 2	N age 3	Catch immatures	Z age 2 to 3	M age 2 to 3
1970	121.05	20.09	39.75	6.38	1.11	0.96
1971	358.88	16.15	173.11	11.55	0.73	0.66
1972	532.79	14.65	295.67	17.86	0.59	0.53
1973	334.05	14.03	163.09	21.96	0.72	0.59
1974	205.80	27.16	98.55	30.30	0.74	0.47
1975	154.49	20.35	75.85	18.63	0.71	0.49
1976	376.96	14.73	113.78	30.35	1.20	0.96
1977	325.15	8.22	155.28	32.13	0.74	0.55
1978	164.15	31.62	48.00	15.95	1.23	0.94
1979	164.53	30.75	56.82	22.23	1.06	0.73
1980	125.94	21.68	38.11	22.91	1.20	0.72
1981	162.97	37.22	48.18	13.27	1.22	0.98
1982	167.44	19.21	20.71	12.13	2.09	1.63
1983	42.32	5.95	3.35	2.59	2.54	1.96
1984	3.05	1.66	0.10	0.00	3.40	3.40
1985	0.60	1.10	0.25	0.00	0.89	0.89
1986	16.89	11.77	2.54	0.00	1.89	1.89
1987	9.66	8.07	16.23	0.00	-0.52	-0.52
1988	62.70	114.88	32.89	1.70	0.65	0.59
1989	483.17	97.02	128.82	8.99	1.32	1.25
1990	172.28	23.98	17.27	2.81	2.30	2.15
1991	47.80	5.58	4.30	0.00	2.41	2.41
1992	1.94	1.49	1.53	0.00	0.23	0.23
1993	3.37	4.77	2.07	0.00	0.49	0.49
1994	2.10	9.43	1.91	0.00	0.10	0.10
1995	24.52	14.58	10.52	0.00	0.85	0.85
1996	35.66	36.98	26.54	0.00	0.30	0.30
1997	47.09	54.39	34.10	0.32	0.32	0.31
1998	49.42	61.13	30.50	0.84	0.48	0.46
1999	150.55	68.19	50.00	1.05	1.10	1.08
2000	73.69	17.31	10.98	0.62	1.90	1.85
2001	6.19	3.40	4.28	0.00	0.37	0.37
2002	9.52	7.02	3.60	0.01	0.97	0.97
2003	5.87	15.05	5.02	0.01	0.16	0.15
2004	4.69	12.33	5.40	0.00	-0.14	-0.14
2005	17.73	32.32	24.58	0.07	-0.33	-0.33
2006	98.42	99.82	50.41	0.29	0.67	0.66
2007	107.94	44.32	66.71	0.62	0.48	0.47
2008	93.61	42.04	58.88	0.14	0.46	0.46
2009	129.21	44.40	92.31	0.43	0.34	0.33
2010	104.25	16.30	67.66	0.07	0.43	0.43
2011	167.09	31.95	36.58	0.06	1.52	1.52
2012	67.70	13.46	12.89	0.88	1.66	1.59
2013	29.33	13.16	2.38	0.00	2.51	2.51
2014	2.51	5.30	14.14	0.00	-1.73	-1.73
2015	51.22	68.23	21.53	0.41	0.87	0.85
2016	24.80	35.42	6.72	0.00	1.31	1.31
2017	3.47	5.97	4.22	0.00	-0.20	-0.20
2018	10.69	19.79	7.28	0.00	0.38	0.38
2019	258.91	70.06	41.19		1.84	

Work conducted during the benchmark meeting

The sections prior to the present were contained in the original WD presented for the benchmark meeting.

The additions in the following were presented during the meeting on request. Figure 4 shows survey mortality based on number of immatures at age 2 in year y versus total number at age 3 in year y+1. The red dots mark the years that were removed in Alternative 1 when deciding which years to include in the estimation of natural mortality in the autumn. These years include all years prior to survey year 1988 (i.e. number of 3-year-olds measured in 1988 compared to number of immature 2-year-olds measured in 1987 is the first comparison included). In addition, they include the survey years 2016 (3-year-olds measured in the abnormal survey year 2016), and 2017 (comparison of 3-year-olds with 2-year-olds measured in the abnormal survey year 2016). The orange dots mark additional years that were removed with Alternative 2. In Alternative 2 all years with low estimated abundance of age 2 capelin (see Fig. 2) have been removed in addition to all years removed with alternative 1.

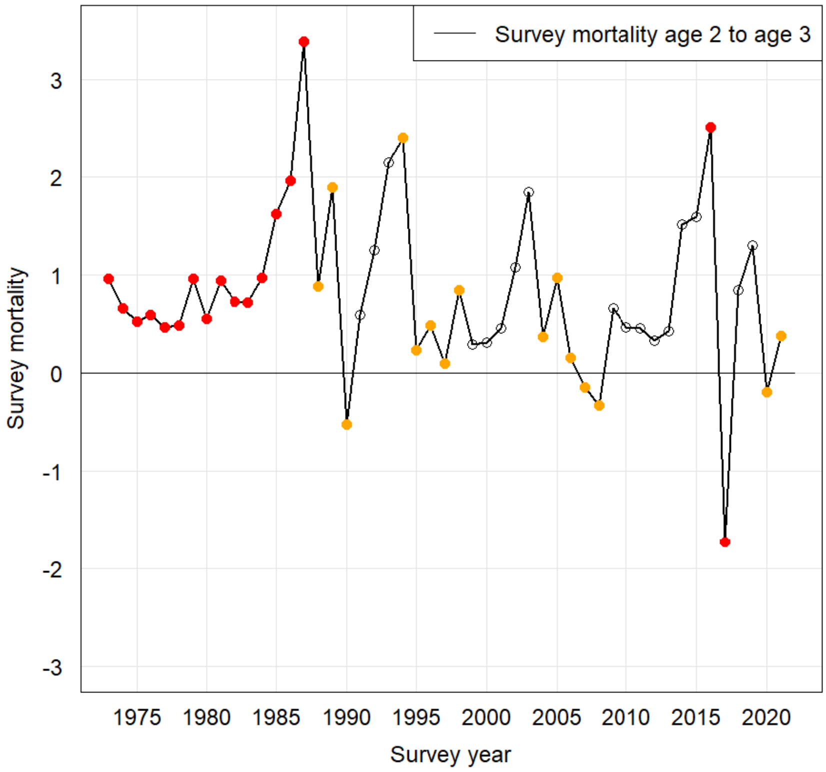

Fig. 4) Survey mortality based on number of immatures at age 2 in year y versus total number at age 3 in year y+1. The survey year on the x-axis refers to year y+1. The red dots mark years that are removed with alternative 1, and the orange dots additional years that are removed with alternative 2 (see text for details).

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Modelling consumption of capelin by cod

Working Document 7, Capelin benchmark, November 2022

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December 7, 2022

Contents

1 Introduction

The Bifrost assessment model for capelin includes a sub model for the consumption of mature capelin in the three first month of a year. This report presents a method for estimating the parameters in the model.

The consumption model starts 1. October in a year with a certain biomass of mature capelin. We call this the survey year. A constant monthly natural mortality rate is assumed for the rest of that year, and in addition there may be mortality due to catch. The catch is usually 0 or small in this period.

In the first three months of the next year, we assume mortality due to catch and consumption by cod only. We call this year the consumption year. The biomass consumption per time unit is a function of available mature capelin biomass and the predation ability of non-mature cod. This function has two parameters, C_{max} and $C_{1/2}$, that are to be estimated from available data.

2 Data

For the moment, we use data from survey years 1991 to 2020 together with consumption years from 1992 to 2021. Data for the survey year 2016 (and consumption year 2017) are ignored, since the survey biomass estimate for this year is unreliable. The following data are available each year:

- Acoustic survey data for biomass of mature capelin per 1. October, in million tons (1 metric ton = 1000 kg).
- We have also swept area survey data for biomass of mature capelin near the ocean bottom. It is possible to add these data to those included in the acoustic survey, to a sum called the composite survey estimate of biomass. *However, we disregard the swept area data for all models in this document.*
- Yearly estimates of natural mortality rate for capelin from 1. October in a survey year to 1. October year. We assume that the monthly mortality rates in October-December are 1/12 of the yearly mortality rates.
- Monthly capelin catch October-December in the survey year and January-March in the consumption year. In million tons.
- For cod in the consumption year, we have the following data for each of the age groups 1 to 10+, where the last group contains cod of age 10 and older.
  - Estimates of number-at age, weight-at-age and fraction of maturity-at- age per 1. January in the consumption year. Numbers are given in billions (10^9) fish and weight is measured in kg.
  - The fraction of non-mature cod which is located in the Svalbard area, and which is assumed not to predate on the mature capelin.
  - Estimates of the yearly natural and fishing mortality rates in the consumption year for the same cod age groups. We assume that the monthly mortality rates in January-March are 1/12 of the yearly mortality rates. *However, for the models in this document, both the fishing and natural mortality rates for cod are set to 0. The reason is that mortality of cod is partly compensated by their increasing weight in the same period.*
  - Estimates of total capelin consumption per cod per month by cod age group (kg/month), based on Norwegian consumption calculation in the first half year. The age groups are originally 1 to 10 and 11+ is a plus groups, but we sum the two upper age groups to a plus group 10+. The estimates are equal for all months January-March. Details on how these data are calculated are given in WD5.
  - The fraction of non-mature capelin in the cod stomachs that must be withdrawn from the total capelin consumption by cod to give the mature capelin consumption by cod.

The cod data is used to calculate a monthly predation ability and empirical estimate of capelin consumption for January-March in the consumption year, se Section 6. It is assumed that the mature capelin is only consumed by the non-mature cod.

The upper panel of Figure 1 shows time plots of some of the basic data (survey biomass 1. October and corresponding catch and empirical consumption). In addition, the survey biomass is projected to 1. January by accounting for a monthly natural mortality rate and catch from 1. October to 1. January. For some years, the empirical consumption is higher than the projected biomass 1. January. This indicates a conflict between the survey and bottom data from 1. October and the empirical consumption.

The lower panel of Figure 1 illustrates this conflict further. The projected biomass 1. January minus the catch and the consumption in the consumption year is negative in 2014 and 2019. Furthermore, the difference is less than 0.2 million tons in additional 13 years, indicating that the biomass may be underestimated or that the empirical consumption may be overestimated.

The empirical consumption tends to increase by increasing available biomass (measured as projected biomass 1. January minus the catch), but tends to stabilise for when the available biomass is about 0.8 million tons (Figure 2).

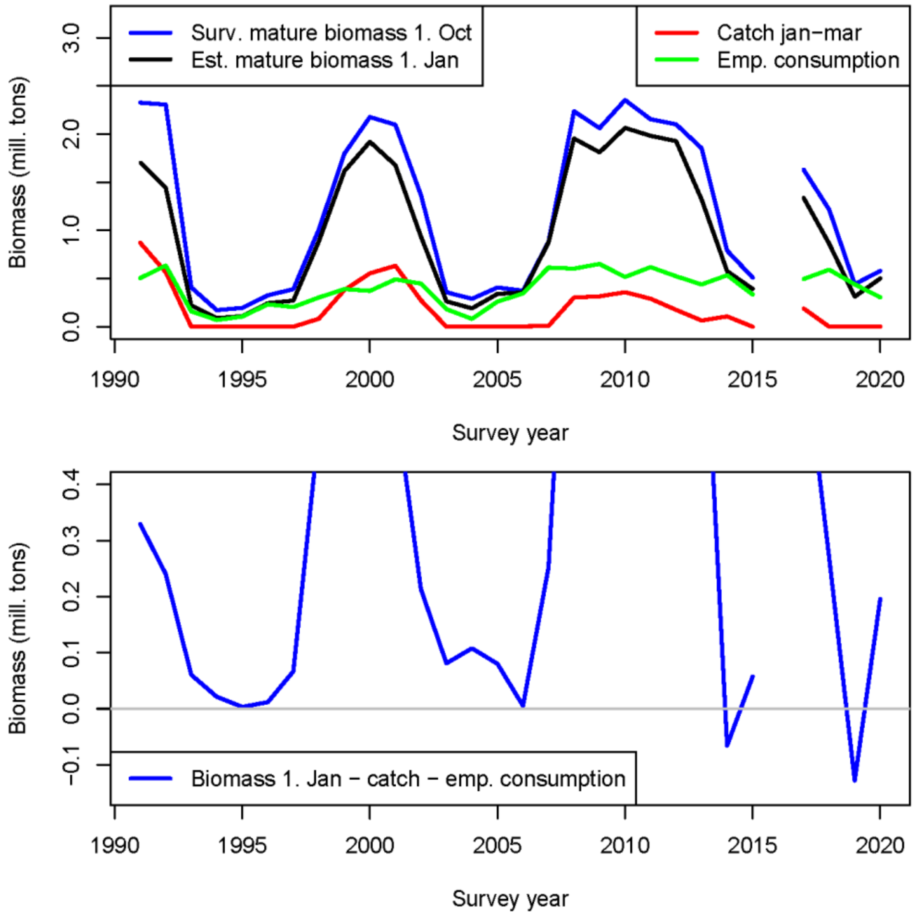

Figure 1: Upper panel: Time plots of survey biomass 1. October, biomass projected to 1. January and the catch and the empirical consumption in January-March. Lower panel: Time plots of projected projected to 1. January minus catch and consumption in the consumption year

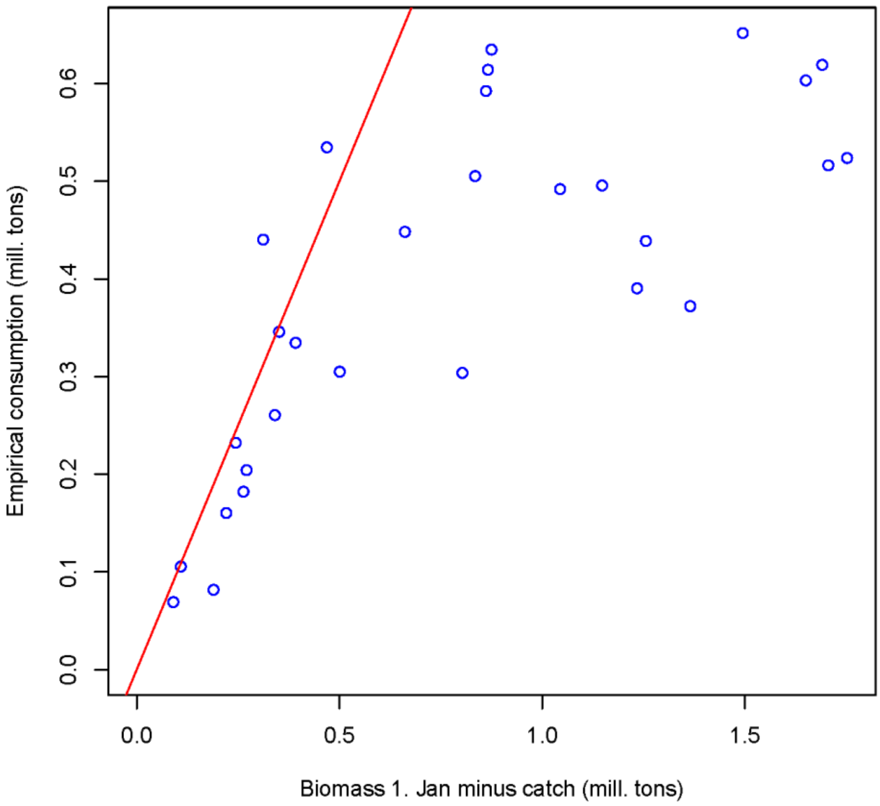

Figure 2: Scatter plot of empirical consumption vs. the biomass projected to 1. January. The red line indicates the one-to-one relationship.

3 Full consumption model

The full consumption model is divided into a population model and a data model. The population model describes how the population of mature capelin evolves from 1. October in the survey year until 1. April in the consumption year. The consumption rate is a central part of the population model, and is a function of the available capelin biomass and the predation ability of cod. Our main goal is to estimate this function. The data model links quantities in the population model to available data.

3.1 Consumption rate

The consumption rate K_t is based on either a Holling's type II or a type III response function and is the instantaneous intake rate of mature capelin by non-mature cod. The type II function is given by

$$K_t = [(C_{max}B_t)/(C_{1/2} + B_t)]P_m, \tag{1}$$

where B_t is the capelin biomass at time t in a month m, P_m is the predation ability for cod (assumed to be constant within a month) and C_{max} and $C_{1/2}$ are parameters to be estimated.

We will also consider a type III function given by

$$K_t = [(C_{max}B_t^2)/(C_{1/2} + B_t^2)]P_m, \tag{2}$$

We will use one month as a time unit for this, but it is important to remember that it is an instantaneous rate, since the rate depends in the capelin biomass itself and because fishing mortality occur at the same time. In the implementation of the model, we approximate this by dividing a month into smaller periods of 1/6 month. This means that within a period of 1/6 month, the consumption is 1/6 K_t.

3.2 Population model

We number October, November and December in the survey year by -2, -1 and 0, and January, February and March in the consumption year by 1, 2 and 3. In the three months of the survey year, we assume that there is a constant natural mortality rate M in each month and that the monthly catch C_m is taken in the middle of each month. Then, the capelin biomass the start of each month, denoted by B_m evolves according to

$$B_{m+1} = (B_m \exp(-M/2) - C_m)\exp(-M/2), \text{for } m = -2, -1, 0. \tag{3}$$

For the three months in the consumption year we divide each months into smaller time intervals $\Delta = 1/6$ month. The catch in that interval is assumed to be $1/\Delta$ of the monthly catch, and we assume that the catch occur before the consumption in each interval. The consumption K_t is calculated by Eqs. (1) or (2) at the start of each time interval after the catch has been withdrawn. The biomass at the start of the next interval is then given by

$$B_{t+\Delta} = B_t - C_m/\Delta - K_t. \tag{4}$$

The recursion starts at the starts at 1. January and ends 1. April.

By adding the K_t's we can calculate the total consumption K_m^{tot} within each of the three months and the total consumption over all three months as $K^{tot} = \sum_{m=1}^{m=3} K_m^{tot}$.

3.3 Data model

Let B^{1Oct} denote the true capelin biomass 1. October and let $\widehat{B}_t^{1Oct}$ denote the corresponding survey estimate. Here we assume first that the survey estimate is error free and unbiased, i.e.

$$B^{1Oct} = \widehat{B}^{1Oct}. \tag{5}$$

We further assume that the estimate $\widehat{K}^{tot}$ for the total consumption in sum over the three months in the consumption year is normally distributed with expectation equal to the true consumption and with a constant variance σ_K^2, i.e.

$$\widehat{K}^{tot} \sim N(K^{tot}, \sigma_K^2). \tag{6}$$

4 Estimation

The parameters are estimated by maximum likelihood by fitting the model to survey observations $\widehat{B}^{1Oct}$ from 1991 to 2020 and to the corresponding empirical consumption estimates $\widehat{K}$. Data for 2016 is not used for estimation, because the survey biomass in this year is unreliable.

Standard errors and confidence intervals for the parameters are found by the bootstrap, where data for each year are re-sampled with replacement. The bootstrap confidence intervals are computed by the percentile method.

This is done by the statistical package R.

5 Results

Table 1 shows the estimates for the parameters in the two models, included standard errors and 95 % confidence intervals. Akaike's' information criterion (AIC) values are also given for comparison between these models, lower values being better. Estimates of the C_{max} parameter are rather insensitive to the model assumptions, and means that a cod of 1 kg eats around 0.16 kg capelin per month when the capelin biomass is large. On the other hand, estimates of $C_{1/2}$ depend on the model assumptions, which means that the estimated consumption at lower biomass is sensitive to model assumptions. This is further due to sensitivity to years with low survey biomass and high empirical consumption.

The model with type III consumption function gives slightly better fit to the data than the type II model (slightly lower AIC value). This model also gives a lower consumption for low capelin biomass (Figure 3). The type III model brings the biomass down to nearly 0 at the 1. April only once, compared to four times for the type II model (the light blue curves in Figures 4-5).

Based on this analysis, the type III model is our preferred model.

Table 1: Parameter estimates with model based and bootstrap standard errors and 95% confidence intervals, and AIC. The unit for C_{max} is kg/month, and for $C_{1/2}$ and β it is million tons.

Consumption function	Parameter	est	se	Conf. int. 2.5%	Conf. int. 97.5%	AIC
2	C_{max}	0.164	0.014	0.138	0.195	-25.2
	$C_{1/2}$	0.106	0.251	0.044	0.762	
	σ_K^2	0.082	0.049	0.065	0.218	
3	C_{max}	0.151	0.007	0.138	0.166	-26.5
	$C_{1/2}$	0.011	0.005	0.000	0.015	
	σ_K^2	0.079	0.021	0.060	0.139	

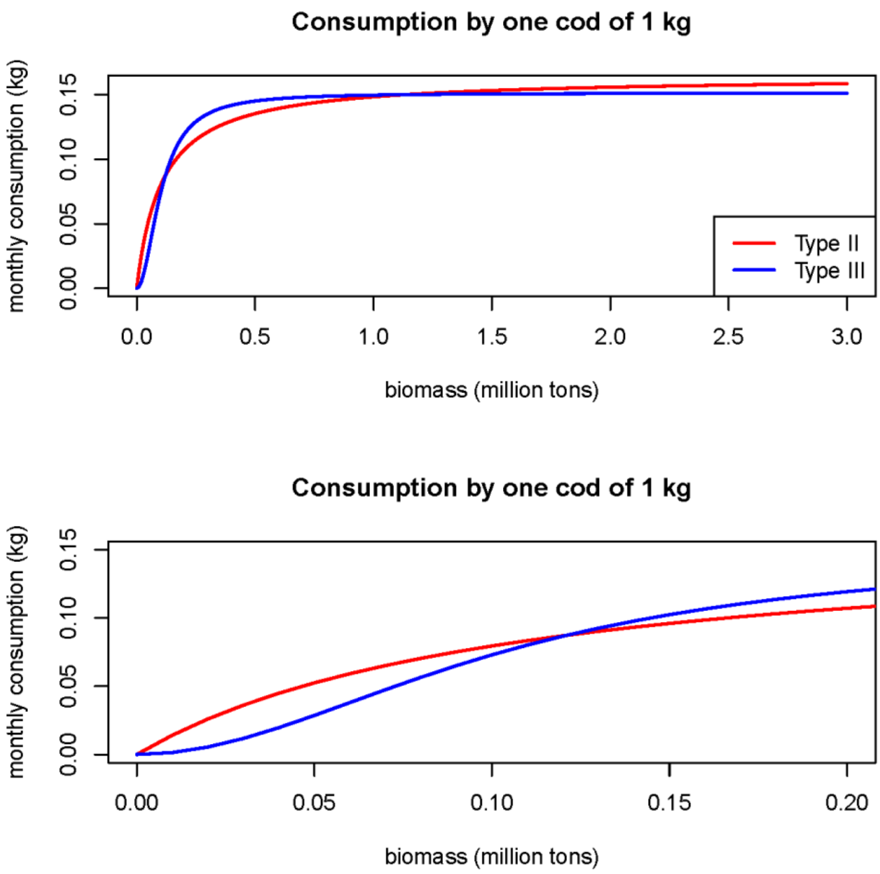

Figure 3: Consumption (or predation) functions for different models. The lower panel focus on small biomass values.

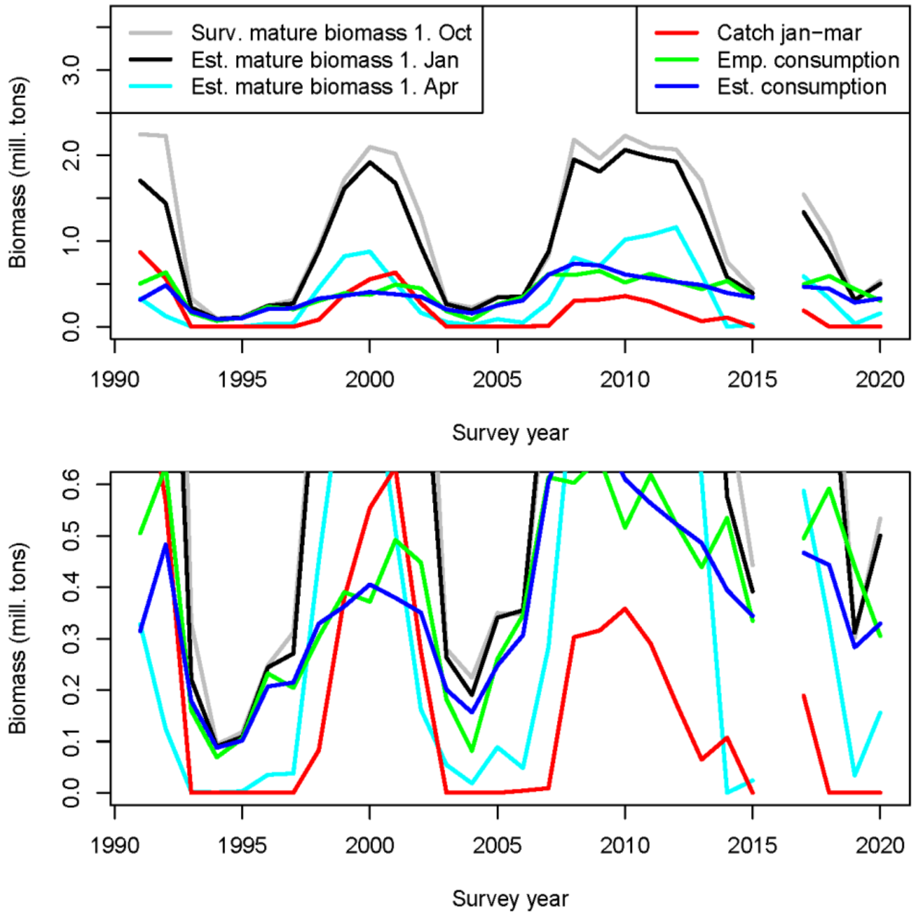

Figure 4: Time plots of results from the model with consumption function of type II: biomass 1. October, biomass projected to 1. January, estimated biomass 1. April, catch and empirical consumption and estimated consumption. The lower panel focus on small biomass values.

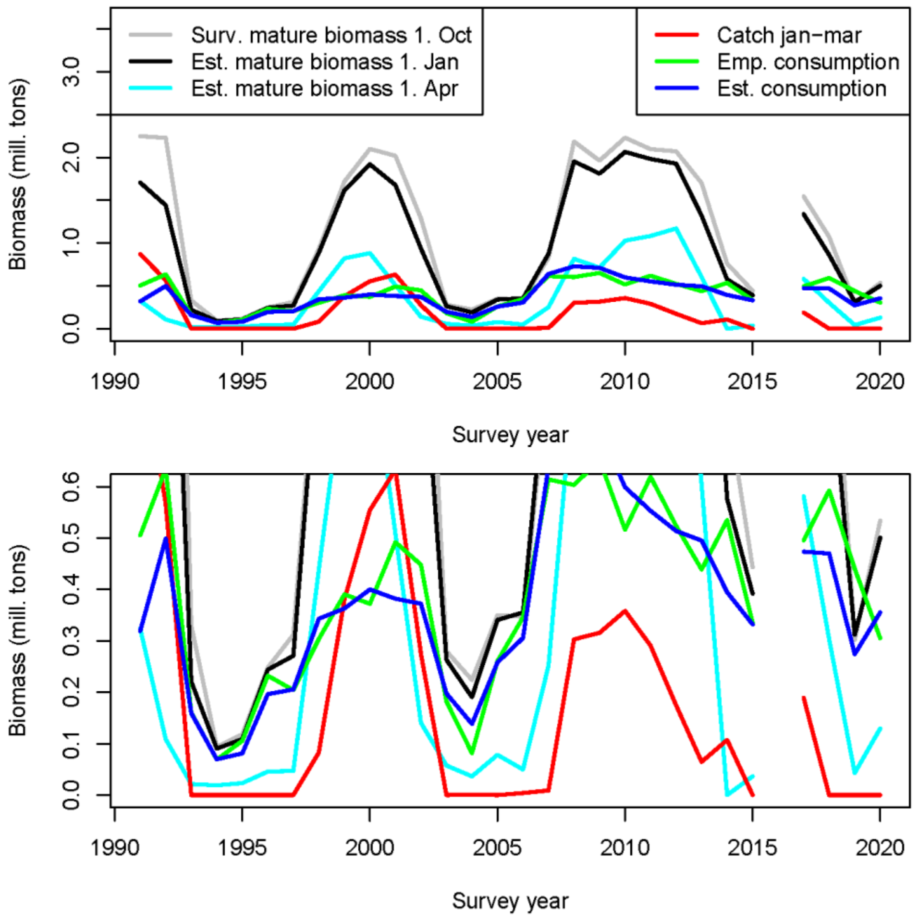

Figure 5: Time plots of results from the model with consumption function of type III.

6 Computation of prediction ability and empirical consumption

For each consumption year, the number of non-mature cod of each age at 1. January the is calculated by

$$N_{1,a} = N_{1,a}^{all}(1 - m_a)(1 - sv_a), a = 1, \ldots, 10+ \tag{7}$$

Here, $N^{all}(1, a)$ is the total number of cod at age a at 1. January, m_a is the fraction of mature cod and sv_a is the fraction of cod that is in the Svalbard area and is irrelevant for the capelin consumption. We assume that the various quantities are known and ignore estimation uncertainties for these.

The yearly age-specific natural and fishing mortality rates M_a^{cod} and F_a^{cod} are used to calculate the number of cod at the beginning of the subsequent months $N_{m+1,a} = N_{m,a} \exp(-(M_a^{cod} + F_a^{cod})/12)$, and in the middle of a month as $N_{m,a}^{mid} = N_{m,a} \exp(-(M_a^{cod} + F_a^{cod})/(2 * 12))$.

The predation ability in a month m is defined by

$$P_m = \sum_{a=1}^{a=10+} S_a N_{m,a}^{mid} W_a^{\theta}. \tag{8}$$

Here, S_a is the suitability of capelin as food for cod at age a. This is a fraction between 0 and 1. It is simply assumed to be 0 for $a = 1$, 0.1 for $a = 2$ and 1 for higher ages. Furthermore, W_a is the weight of cod at age a, which is assumed to be constant within a year). Finally, $\theta = 0.801$.

We calculate an empirical estimate $\widehat{K}_m^{tot}$ of the capelin consumption by cod in month m by

$$\widehat{K}_m^{tot} = f^{mat} \sum_{a=1}^{a=10+} N_{m,a}^{mid} k_a, \tag{9}$$

where k_a is an age-specific estimate of the monthly capelin consumption per cod. The factor f^{mat} is the yearly fraction of mature capelin in the cod stomachs (the data is given as the non-mature fraction $1 - f^{mat}$). The empirical estimate of the total consumption in all three months is then $\widehat{K}^{tot} = \sum_{m=1}^{m=3} \widehat{K}_m^{tot}$.

All quantities above depend on year except the suitability S_a and the parameter θ. Note that the natural and fishing mortalities rates for cod, M_a^{cod} and F_a^{cod}, are set to 0 for the models estimated here.

7 Data tables

Survey biomass ($\widehat{B}^{1Oct}$) in the survey year, monthly (K_m^{tot}) and sum (K^{tot}) of empirical consumption and monthly prediction ability (P_m) in the corresponding consumption year, in million tons. Since both the natural and fishing mortality rates for cod are assumed to be 0, the predation ability and the emprical consumption are the same for all months.

Survey	Survey	Empirical consumption				Predation ability		
year	biomass	jan	feb	mar	sum	jan	feb	mar
1991	2.248	0.168	0.168	0.168	0.505	0.716	0.716	0.716
1992	2.228	0.212	0.212	0.212	0.635	1.167	1.167	1.167
1993	0.330	0.053	0.053	0.053	0.160	1.220	1.220	1.220
1994	0.094	0.023	0.023	0.023	0.069	1.053	1.053	1.053
1995	0.118	0.035	0.035	0.035	0.106	0.907	0.907	0.907
1996	0.248	0.077	0.077	0.077	0.232	0.814	0.814	0.814
1997	0.312	0.068	0.068	0.068	0.204	0.825	0.825	0.825
1998	0.931	0.101	0.101	0.101	0.304	0.775	0.775	0.775
1999	1.718	0.130	0.130	0.130	0.390	0.807	0.807	0.807
2000	2.099	0.124	0.124	0.124	0.372	0.886	0.886	0.886
2001	2.019	0.164	0.164	0.164	0.492	0.852	0.852	0.852
2002	1.290	0.149	0.149	0.149	0.448	0.883	0.883	0.883
2003	0.280	0.061	0.061	0.061	0.182	0.727	0.727	0.727
2004	0.224	0.027	0.027	0.027	0.082	0.768	0.768	0.768
2005	0.350	0.087	0.087	0.087	0.261	0.780	0.780	0.780
2006	0.347	0.115	0.115	0.115	0.346	1.022	1.022	1.022
2007	0.829	0.205	0.205	0.205	0.614	1.468	1.468	1.468
2008	2.185	0.201	0.201	0.201	0.603	1.615	1.615	1.615
2009	1.962	0.217	0.217	0.217	0.652	1.577	1.577	1.577
2010	2.230	0.172	0.172	0.172	0.516	1.325	1.325	1.325
2011	2.096	0.206	0.206	0.206	0.619	1.224	1.224	1.224
2012	2.071	0.175	0.175	0.175	0.524	1.137	1.137	1.137
2013	1.701	0.146	0.146	0.146	0.439	1.106	1.106	1.106
2014	0.760	0.178	0.178	0.178	0.535	1.311	1.311	1.311
2015	0.443	0.112	0.112	0.112	0.335	1.240	1.240	1.240
2016	0.153	0.152	0.152	0.152	0.455	0.917	0.917	0.917
2017	1.545	0.165	0.165	0.165	0.496	1.057	1.057	1.057
2018	1.071	0.197	0.197	0.197	0.592	1.080	1.080	1.080
2019	0.302	0.147	0.147	0.147	0.440	1.026	1.026	1.026
2020	0.534	0.102	0.102	0.102	0.305	0.905	0.905	0.905

Monthly natural mortality rate for mature capelin (M) in October-December in the survey year.

```
Survey
year
1991 0.110162706
1992 0.191664706
1993 0.200752071
1994 0.019438473
1995 0.040598154
1996 0.007954432
1997 0.070533420
1998 0.024613840
1999 0.026894496
2000 0.040222415
2001 0.09185436
2002 0.158656896
2003 0.030782871
2004 0.080949013
2005 0.012943005
2006 -0.011703217
2007 -0.027214053
2008 0.055767038
2009 0.040097973
2010 0.038634691
2011 0.028030067
2012 0.036021462
2013 0.126582637
2014 0.138247856
2015 0.061214257
2016 NA
2017 0.072234559
2018 0.10879488
2019 -0.016326456
2020 0.032041859
```

Monthly catch of mature capelin (C_m) in October-December in the survey year, and in January-March in the corresponding consumption year, in million tons.

Survey year	oct	nov	dec	jan	feb	mar
1991	0.061611	0.047854	0.014520	0.058251	0.334785	0.478086
1992	0.047622	0.045550	0.017898	0.035492	0.198564	0.332221
1993	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1994	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1995	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1996	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1997	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1998	0.000000	0.000000	0.000000	0.000920	0.008908	0.073095
1999	0.004956	0.008918	0.005555	0.226944	0.041158	0.112197
2000	0.006300	0.011337	0.007062	0.024335	0.184291	0.345777
2001	0.000313	0.002856	0.006876	0.086711	0.180387	0.365679
2002	0.000000	0.002454	0.011904	0.071580	0.030160	0.173678
2003	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2004	0.000000	0.000000	0.000000	0.000000	0.000000	0.000952
2005	0.000219	0.000000	0.000000	0.000000	0.000000	0.000000
2006	0.000000	0.000000	0.000000	0.000000	0.000000	0.003996
2007	0.000000	0.000000	0.000000	0.000000	0.000000	0.008995
2008	0.001076	0.000000	0.000000	0.008449	0.035117	0.259386
2009	0.000000	0.000000	0.000000	0.000000	0.067587	0.248230
2010	0.000000	0.000000	0.000000	0.000000	0.104201	0.254095
2011	0.000000	0.000000	0.000000	0.000000	0.078627	0.212084
2012	0.000000	0.000000	0.000000	0.004712	0.080601	0.089442
2013	0.000000	0.000000	0.000000	0.000353	0.026389	0.037966
2014	0.000000	0.000000	0.000000	0.000000	0.015025	0.092313
2015	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2016	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2017	0.000000	0.000000	0.000000	0.000000	0.038457	0.150700
2018	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2019	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2020	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Fraction of non-mature capelin in the cod stomachs $(1 - f^{mat})$ in the consumption year.

```
Cons.
year fraction non-matrure
1991 0.28363768
1992 0.28363768
1993 0.33032208
1994 0.55810619
1995 0.68081722
1996 0.30139627
1997 0.17056895
1998 0.21332873
1999 0.20166148
2000 0.16270377
2001 0.22053141
2002 0.08898833
2003 0.21497572
2004 0.44493342
2005 0.68004612
2006 0.31683089
2007 0.14805177
2008 0.23221805
2009 0.24553627
2010 0.21133859
2011 0.33724455
2012 0.29440866
2013 0.20391299
2014 0.30270047
2015 0.32013247
2017 0.04988397
2018 0.15957137
2019 0.17968026
2020 0.22098912
```

Monthly capelin consumption by cod at age a, k_a, in the consumption year (kg/month).

Cons.

year	1	2	3	4	5	6	7	8	9	10	11+
1992	0.0025	0.0600	0.1643	0.2495	0.2332	0.2739	0.3793	0.3967	0.3605	0.3914	0.3920
1993	0.0000	0.0303	0.1112	0.2523	0.4283	0.5594	0.8167	0.8238	0.8653	0.9095	0.9418
1994	0.0000	0.0185	0.0373	0.0599	0.1078	0.1809	0.1929	0.2012	0.2135	0.2203	0.2248
1995	0.0002	0.0071	0.0419	0.0414	0.0551	0.0625	0.0311	0.0211	0.0229	0.0241	0.0250
1996	0.0000	0.0064	0.0162	0.0245	0.0436	0.0786	0.0710	0.0758	0.0501	0.0525	0.0538
1997	0.0011	0.0034	0.0483	0.0450	0.0752	0.1038	0.1328	0.2904	0.3450	0.3626	0.3605
1998	0.0002	0.0064	0.0439	0.0759	0.0483	0.0885	0.1060	0.2284	0.0573	0.0624	0.0635
1999	0.0000	0.0082	0.0306	0.1151	0.1823	0.2256	0.2396	0.3415	0.1396	0.1551	0.1582
2000	0.0000	0.0156	0.0643	0.1240	0.1800	0.2292	0.1961	0.3535	0.1405	0.1486	0.1560
2001	0.0025	0.0116	0.0759	0.1209	0.1637	0.2301	0.3631	0.5138	0.3962	0.4302	0.4471
2002	0.0021	0.0223	0.0711	0.1520	0.2075	0.2643	0.3222	0.3094	0.1271	0.1386	0.1396
2003	0.0000	0.0337	0.0830	0.1387	0.2226	0.3281	0.4619	0.3545	0.4458	0.4710	0.5230
2004	0.0000	0.0150	0.0541	0.0860	0.1355	0.1944	0.2530	0.4417	0.9150	1.0034	1.0187
2005	0.0012	0.0205	0.0412	0.0766	0.0786	0.1278	0.1231	0.0410	0.0634	0.0687	0.0750
2006	0.0000	0.0188	0.0712	0.0875	0.1460	0.1745	0.2702	0.4449	0.3542	0.3841	0.4195
2007	0.0000	0.0115	0.0404	0.0953	0.1605	0.1817	0.2382	0.3306	0.2987	0.3204	0.3396
2008	0.0005	0.0256	0.0698	0.1396	0.1942	0.3453	0.4223	0.5344	0.5363	0.5675	0.5846
2009	0.0011	0.0099	0.0714	0.1461	0.1861	0.2116	0.2901	0.4080	0.1909	0.2054	0.2094
2010	0.0006	0.0250	0.0748	0.1535	0.1891	0.2338	0.3880	0.5481	0.6193	0.6498	0.6738
2011	0.0022	0.0234	0.0794	0.1382	0.1836	0.3026	0.3458	0.3235	0.5618	0.6049	0.6153
2012	0.0040	0.0373	0.0887	0.1486	0.2183	0.2192	0.2908	0.4431	0.6098	0.6623	0.5810
2013	0.0000	0.0172	0.0898	0.1439	0.2326	0.2806	0.2202	0.2781	0.4735	0.5193	0.4679
2014	0.0001	0.0082	0.0749	0.1517	0.2487	0.1757	0.2227	0.3048	0.3672	0.3937	0.3526
2015	0.0000	0.0202	0.0816	0.1342	0.2221	0.2914	0.3892	0.2481	0.5591	0.5989	0.6845
2016	0.0000	0.0134	0.0784	0.1165	0.1391	0.2033	0.2615	0.1779	0.3258	0.3441	0.4134
2017	0.0026	0.0206	0.0733	0.1044	0.1748	0.2487	0.2631	0.2539	0.2912	0.3121	0.3832
2018	0.0000	0.0245	0.0761	0.1351	0.1822	0.2254	0.2712	0.5769	0.7269	0.7776	0.5559
2019	0.0015	0.0184	0.0648	0.1423	0.2172	0.2732	0.3601	0.4672	0.4615	0.4871	0.6354
2020	0.0013	0.0066	0.0523	0.1376	0.1751	0.2142	0.2531	0.3665	0.1904	0.2494	0.3112
2021	0.0011	0.0136	0.0328	0.0718	0.1518	0.2311	0.2522	0.4145	0.3716	0.3939	0.4784

Total number of cod per age group 1. January in the consumption year, $N^{all}_{1,a}$. In billions.

Cons. year	1	2	3	4	5	6	7	8	9	10
1992	2.764127	1.369365	0.716809	0.272016	0.101011	0.069155	0.048733	0.033921	0.046453	0.006094
1993	21.902539	1.451857	0.990119	0.504157	0.241432	0.072816	0.036846	0.023561	0.015535	0.024035
1994	9.405128	1.379221	0.752658	0.734832	0.400366	0.147087	0.039093	0.015947	0.010672	0.006403
1995	19.640189	1.335519	0.539812	0.493577	0.525544	0.232089	0.063132	0.012508	0.005327	0.003446
1996	28.241937	2.589398	0.405894	0.304709	0.337363	0.283121	0.104043	0.019861	0.004303	0.001589
1997	21.327846	3.400774	0.783453	0.210101	0.205596	0.183110	0.120012	0.037458	0.006314	0.001652
1998	7.890580	1.414785	1.059540	0.477806	0.127297	0.098038	0.070990	0.041641	0.009521	0.001630
1999	3.485480	1.253516	0.630159	0.604406	0.264735	0.062506	0.032948	0.026060	0.011642	0.002527
2000	3.542006	0.934054	0.749764	0.410834	0.377249	0.122599	0.024473	0.011241	0.007424	0.002656
2001	4.334560	0.585257	0.593562	0.535126	0.291773	0.185130	0.052027	0.009006	0.003415	0.001939
2002	1.013636	1.375658	0.375075	0.431865	0.368919	0.186553	0.082287	0.020388	0.003117	0.001189
2003	6.369200	0.416105	0.759779	0.288708	0.288362	0.235921	0.084519	0.030369	0.006787	0.001147
2004	3.647648	1.479871	0.243027	0.577509	0.215419	0.182849	0.116496	0.033995	0.010997	0.002654
2005	5.452305	0.807287	0.697364	0.186451	0.407267	0.136600	0.094486	0.039298	0.011278	0.004002
2006	4.149250	1.706951	0.539345	0.470095	0.141844	0.232607	0.068968	0.034190	0.013769	0.003414
2007	2.277513	1.456894	1.259517	0.439814	0.305605	0.089468	0.120749	0.030555	0.012807	0.004650
2008	1.280846	0.816936	1.017985	0.976289	0.337459	0.169025	0.053247	0.063615	0.015827	0.005829
2009	9.108218	0.409001	0.590038	0.795485	0.745082	0.250581	0.090127	0.034070	0.029401	0.008128
2010	9.312668	0.777176	0.204469	0.459238	0.654988	0.553101	0.170159	0.055001	0.019389	0.015158
2011	7.004132	1.125840	0.362283	0.183687	0.382331	0.539606	0.392561	0.087459	0.032100	0.010950
2012	16.704098	1.709359	0.509539	0.278784	0.148118	0.318532	0.409532	0.223437	0.045996	0.016640
2013	7.040800	2.790923	0.472255	0.373104	0.228605	0.130017	0.244523	0.268796	0.139194	0.024118
2014	7.669852	1.378466	0.860386	0.362190	0.300542	0.184030	0.103257	0.172721	0.150851	0.068053
2015	13.720626	0.699012	0.457348	0.579081	0.304387	0.216038	0.134295	0.069381	0.100654	0.078138
2016	4.160529	1.529754	0.289567	0.320014	0.424662	0.218679	0.138182	0.078203	0.045580	0.055989
2017	3.196245	1.065241	0.788999	0.244082	0.231861	0.292021	0.149931	0.080467	0.042529	0.025522
2018	17.665529	1.132683	0.510445	0.552851	0.192821	0.163927	0.191443	0.089215	0.041563	0.022753
2019	11.096805	1.672978	0.666503	0.381061	0.401157	0.154720	0.095668	0.112423	0.049075	0.020655
2020	7.175417	0.901201	0.568171	0.447081	0.288610	0.261056	0.106551	0.057499	0.059802	0.024839
2021	3.000000	3.114860	0.406025	0.368619	0.329704	0.200343	0.155439	0.057711	0.029745	0.028086

Fractions of mature-at-age for cod in the consumption year, m_a.

Cons. year	1	2	3	4	5	6	7	8	9	10
1992	0	0	0.001	0.014	0.145	0.419	0.800	0.943	0.974	1.000
1993	0	0	0.000	0.028	0.087	0.368	0.704	0.931	0.972	0.994
1994	0	0	0.000	0.005	0.119	0.336	0.583	0.876	0.965	0.990
1995	0	0	0.000	0.005	0.060	0.373	0.614	0.748	0.955	0.980
1996	0	0	0.000	0.000	0.016	0.252	0.619	0.817	0.975	1.000
1997	0	0	0.000	0.000	0.014	0.140	0.597	0.842	0.950	0.967
1998	0	0	0.000	0.005	0.031	0.168	0.468	0.828	0.956	0.980
1999	0	0	0.000	0.001	0.014	0.170	0.506	0.841	0.961	1.000
2000	0	0	0.000	0.000	0.066	0.261	0.699	0.872	0.978	1.000
2001	0	0	0.001	0.006	0.069	0.378	0.646	0.851	0.955	1.000
2002	0	0	0.001	0.015	0.085	0.412	0.695	0.846	0.970	1.000
2003	0	0	0.001	0.000	0.089	0.331	0.662	0.882	0.960	1.000
2004	0	0	0.000	0.009	0.092	0.438	0.728	0.883	0.973	0.974
2005	0	0	0.000	0.003	0.066	0.366	0.720	0.897	0.971	0.991
2006	0	0	0.000	0.015	0.061	0.367	0.633	0.907	0.961	1.000
2007	0	0	0.000	0.007	0.076	0.370	0.719	0.884	0.977	1.000
2008	0	0	0.005	0.008	0.082	0.309	0.539	0.869	0.928	0.994
2009	0	0	0.000	0.000	0.081	0.362	0.745	0.859	0.978	0.997
2010	0	0	0.005	0.006	0.060	0.335	0.552	0.838	0.931	0.971
2011	0	0	0.000	0.000	0.040	0.339	0.644	0.798	0.932	0.963
2012	0	0	0.001	0.000	0.058	0.209	0.544	0.799	0.930	0.967
2013	0	0	0.000	0.000	0.010	0.156	0.482	0.763	0.913	0.982
2014	0	0	0.000	0.000	0.025	0.137	0.516	0.806	0.935	0.984
2015	0	0	0.000	0.001	0.004	0.074	0.282	0.681	0.891	0.963
2016	0	0	0.000	0.000	0.002	0.057	0.256	0.569	0.832	0.955
2017	0	0	0.000	0.018	0.003	0.148	0.463	0.749	0.931	0.990
2018	0	0	0.000	0.003	0.028	0.207	0.478	0.731	0.916	0.971
2019	0	0	0.000	0.000	0.010	0.126	0.466	0.842	0.942	0.968
2020	0	0	0.000	0.000	0.014	0.112	0.356	0.775	0.904	0.955
2021	0	0	0.002	0.002	0.006	0.140	0.386	0.657	0.893	0.974

Age-specific fractions of cod in the Svalbard area in the consumption year, sv_a.

Cons. year	1	2	3	4	5	6	7	8	9	10
1992	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1993	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1994	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1995	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1996	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1997	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1998	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
1999	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2000	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2001	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2002	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2003	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2004	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2005	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2006	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2007	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2008	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2009	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2010	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2011	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2012	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2013	0.3179	0.2811	0.2219	0.2422	0.2081	0.1842	0.1573	0.1311	0.1178	0.110
2014	0.5720	0.4050	0.1890	0.2000	0.1740	0.1760	0.0890	0.1000	0.1010	0.052
2015	0.2460	0.2490	0.1840	0.2040	0.1410	0.1040	0.0710	0.0620	0.0460	0.087
2016	0.3240	0.3040	0.2740	0.1790	0.1500	0.0830	0.0770	0.0880	0.0460	0.056
2017	0.2840	0.3840	0.3370	0.4450	0.3420	0.3480	0.2710	0.1250	0.0730	0.065
2018	0.3720	0.2300	0.2080	0.2310	0.2160	0.1810	0.1950	0.1560	0.1670	0.076
2019	0.2760	0.2130	0.1430	0.1870	0.1930	0.1590	0.2090	0.2190	0.1750	0.236
2020	0.1540	0.1110	0.1540	0.2110	0.1710	0.1860	0.1640	0.1780	0.1950	0.180
2021	0.3950	0.3580	0.2040	0.2720	0.2370	0.2730	0.1980	0.1220	0.1550	0.172

Weight-at-age of cod on in the consumption year, W_a, in kg.

Cons. year	1	2	3	4	5	6	7	8	9	10
1992	0.023	0.112	0.440	0.931	1.812	2.716	3.895	5.176	6.774	9.598
1993	0.011	0.076	0.344	1.172	1.820	2.823	4.031	5.497	6.765	8.571
1994	0.012	0.053	0.237	0.757	1.419	2.458	3.845	5.374	6.648	7.653
1995	0.014	0.063	0.197	0.487	1.141	2.118	3.504	4.915	6.949	9.051
1996	0.013	0.061	0.206	0.482	0.980	2.041	3.520	5.507	7.740	9.922
1997	0.010	0.059	0.211	0.537	1.110	1.876	3.381	5.258	8.546	10.653
1998	0.010	0.058	0.242	0.561	1.179	1.936	2.944	4.583	7.092	10.700
1999	0.010	0.058	0.209	0.514	1.183	2.007	3.037	4.479	6.512	10.028
2000	0.014	0.068	0.194	0.465	1.218	1.963	3.064	4.120	5.746	7.157
2001	0.011	0.089	0.284	0.513	1.210	2.250	3.299	5.066	6.373	9.290
2002	0.012	0.063	0.230	0.603	1.184	2.138	3.336	4.810	6.912	8.809
2003	0.011	0.074	0.233	0.551	1.317	2.022	3.239	4.984	6.727	8.422
2004	0.009	0.054	0.240	0.550	1.074	2.038	2.911	4.402	6.263	8.535
2005	0.010	0.056	0.225	0.610	1.083	1.870	3.002	3.971	5.789	8.127
2006	0.013	0.065	0.252	0.591	1.219	2.014	3.028	4.434	5.999	7.774
2007	0.016	0.075	0.249	0.663	1.329	2.127	3.183	4.590	6.477	8.880
2008	0.013	0.095	0.286	0.726	1.418	2.410	3.331	4.914	6.747	8.851
2009	0.010	0.071	0.274	0.652	1.353	2.312	3.803	5.103	6.750	9.252
2010	0.014	0.059	0.258	0.608	1.208	2.010	3.088	4.903	6.498	7.992
2011	0.012	0.059	0.225	0.600	1.097	1.926	2.861	4.403	6.531	8.648
2012	0.012	0.058	0.227	0.555	1.182	1.834	2.831	4.124	6.056	8.584
2013	0.010	0.064	0.247	0.577	1.134	1.998	2.841	4.015	5.523	8.077
2014	0.008	0.057	0.216	0.577	1.137	1.791	2.781	3.850	5.245	6.992
2015	0.007	0.054	0.229	0.540	1.134	1.934	2.753	4.081	5.315	7.135
2016	0.012	0.055	0.210	0.536	1.001	1.812	2.720	3.958	5.640	7.064
2017	0.013	0.055	0.255	0.675	1.107	1.896	2.826	4.158	5.700	7.628
2018	0.017	0.068	0.286	0.620	1.188	1.949	2.768	4.059	5.749	7.380
2019	0.011	0.043	0.240	0.603	1.085	1.820	3.025	4.296	5.891	7.293
2020	0.012	0.041	0.148	0.503	1.055	1.692	2.590	4.064	5.617	7.673
2021	0.014	0.066	0.170	0.437	0.954	1.718	2.669	3.804	5.822	7.396

Age-specific yearly natural mortality rate of cod in the consumption year, M_a^{cod}.
These are not used in the models in this document, but replaced by 0.

Cons. year	1	2	3	4	5	6	7	8	9	10
1992	0.644	0.324	0.207	0.200	0.200	0.202	0.2	0.2	0.2	0.2
1993	2.765	0.656	0.241	0.200	0.200	0.200	0.2	0.2	0.2	0.2
1994	1.951	0.939	0.348	0.261	0.215	0.220	0.2	0.2	0.2	0.2
1995	2.023	1.188	0.531	0.315	0.228	0.203	0.2	0.2	0.2	0.2
1996	2.131	1.195	0.524	0.327	0.244	0.218	0.2	0.2	0.2	0.2
1997	2.733	1.165	0.421	0.269	0.242	0.227	0.2	0.2	0.2	0.2
1998	1.844	0.808	0.429	0.274	0.220	0.269	0.2	0.2	0.2	0.2
1999	1.318	0.514	0.264	0.234	0.238	0.224	0.2	0.2	0.2	0.2
2000	1.803	0.453	0.248	0.212	0.244	0.226	0.2	0.2	0.2	0.2
2001	1.149	0.445	0.236	0.220	0.200	0.231	0.2	0.2	0.2	0.2
2002	0.891	0.594	0.278	0.212	0.200	0.224	0.2	0.2	0.2	0.2
2003	1.461	0.538	0.239	0.200	0.200	0.212	0.2	0.2	0.2	0.2
2004	1.513	0.754	0.250	0.215	0.200	0.200	0.2	0.2	0.2	0.2
2005	1.165	0.403	0.298	0.212	0.215	0.200	0.2	0.2	0.2	0.2
2006	1.051	0.305	0.203	0.228	0.200	0.207	0.2	0.2	0.2	0.2
2007	1.029	0.360	0.247	0.200	0.247	0.200	0.2	0.2	0.2	0.2
2008	1.140	0.326	0.258	0.213	0.200	0.233	0.2	0.2	0.2	0.2
2009	2.460	0.694	0.274	0.209	0.200	0.200	0.2	0.2	0.2	0.2
2010	2.112	0.764	0.296	0.235	0.207	0.200	0.2	0.2	0.2	0.2
2011	1.411	0.794	0.423	0.313	0.200	0.200	0.2	0.2	0.2	0.2
2012	1.774	1.290	0.380	0.300	0.200	0.200	0.2	0.2	0.2	0.2
2013	1.652	1.182	0.393	0.235	0.205	0.200	0.2	0.2	0.2	0.2
2014	2.405	1.103	0.370	0.294	0.212	0.200	0.2	0.2	0.2	0.2
2015	2.192	0.880	0.356	0.262	0.235	0.204	0.2	0.2	0.2	0.2
2016	1.358	0.658	0.216	0.256	0.265	0.216	0.2	0.2	0.2	0.2
2017	1.033	0.728	0.395	0.218	0.214	0.200	0.2	0.2	0.2	0.2
2018	2.369	0.525	0.272	0.212	0.200	0.216	0.2	0.2	0.2	0.2
2019	2.322	1.054	0.306	0.217	0.213	0.200	0.2	0.2	0.2	0.2
2020	1.500	0.650	0.431	0.236	0.200	0.210	0.2	0.2	0.2	0.2
2021	1.500	0.656	0.402	0.272	0.256	0.200	0.2	0.2	0.2	0.2

Age-specific yearly fishing mortality rate of cod in the consumption year, F_a^{cod}. These are not used in the models in this document, but replaced by 0.

Cons. year	1	2	3	4	5	6	7	8	9	10
1992	0	0	0.024	0.114	0.280	0.429	0.528	0.554	0.563	0.556
1993	0	0	0.014	0.110	0.315	0.522	0.617	0.657	0.691	0.707
1994	0	0	0.012	0.109	0.322	0.596	0.920	0.913	0.869	0.846
1995	0	0	0.014	0.116	0.323	0.606	0.930	0.894	0.947	0.918
1996	0	0	0.021	0.133	0.352	0.619	0.885	0.937	0.854	1.094
1997	0	0	0.022	0.168	0.444	0.683	0.897	1.199	1.125	1.260
1998	0	0	0.026	0.180	0.471	0.710	0.855	1.159	1.133	1.306
1999	0	0	0.015	0.148	0.460	0.680	0.869	1.099	1.218	1.289
2000	0	0	0.009	0.113	0.363	0.586	0.831	1.016	1.103	1.176
2001	0	0	0.009	0.095	0.293	0.531	0.754	0.922	0.884	1.038
2002	0	0	0.008	0.090	0.276	0.520	0.772	0.881	0.831	0.780
2003	0	0	0.010	0.088	0.284	0.474	0.726	0.807	0.768	0.727
2004	0	0	0.010	0.090	0.292	0.499	0.762	0.850	0.885	0.921
2005	0	0	0.011	0.102	0.317	0.515	0.733	0.858	0.937	0.862
2006	0	0	0.016	0.102	0.280	0.440	0.613	0.730	0.787	0.763
2007	0	0	0.017	0.091	0.240	0.347	0.446	0.536	0.550	0.516
2008	0	0	0.011	0.069	0.162	0.275	0.367	0.442	0.475	0.427
2009	0	0	0.010	0.058	0.132	0.220	0.315	0.351	0.450	0.360
2010	0	0	0.009	0.049	0.106	0.177	0.278	0.373	0.387	0.409
2011	0	0	0.006	0.048	0.105	0.160	0.253	0.348	0.438	0.519
2012	0	0	0.006	0.046	0.118	0.160	0.239	0.322	0.411	0.470
2013	0	0	0.007	0.048	0.122	0.189	0.267	0.358	0.436	0.501
2014	0	0	0.008	0.053	0.141	0.227	0.311	0.387	0.411	0.499
2015	0	0	0.010	0.055	0.148	0.267	0.321	0.389	0.357	0.487
2016	0	0	0.009	0.052	0.147	0.255	0.337	0.411	0.397	0.533
2017	0	0	0.010	0.056	0.150	0.268	0.350	0.467	0.462	0.567
2018	0	0	0.011	0.058	0.156	0.263	0.359	0.446	0.502	0.616
2019	0	0	0.009	0.060	0.155	0.251	0.365	0.478	0.495	0.648
2020	0	0	0.009	0.059	0.165	0.276	0.394	0.498	0.561	0.677
2021	0	0	0.009	0.058	0.190	0.335	0.458	0.531	0.665	0.710

WD_BS8 Revision of the basis for the capelin Blim

Georg Skaret, Bjarte Bogstad, Sondre Hølleland

Background

A target escapement management strategy is used in the management for the Barents Sea capelin stock. The history of harvest control rules and reference points was reviewed in Gjøsæter et al. (2002). The management approach is based on a limit reference point – $\mathbf{B}_{\mathrm{lim}}$ at 200 000 tons based on the following rationale*: "For this stock, a* $\boldsymbol{B_{lim}}$ *equal to the 1989 spawning stock biomass, which is the lowest SSB having produced an outstanding year class, at least after 1980, is considered a good basis for such a reference point in a non-herring situation. The median value of the 1989 spawning stock biomass is 96 000 t. The assessment model may not yet account for all sources of uncertainty, and there are inconsistencies in the data series. Thus, it may be appropriate to use a somewhat higher* $\boldsymbol{B_{lim}}$*. In recent years ICES has used a* $\boldsymbol{B_{lim}}$ *of 200 000 t."*

After this, ACFM has continued to use a $\mathbf{B}_{\mathrm{lim}}$ set to a fixed value of 200 000 t and the Mixed Norwegian-Russian Fishery Commission re-stated at its 50th session in autumn 2020: *The Parties confirmed the harvest control rule for capelin, where the TAC is not set higher than that, with 95% probability, at least 200 000 tonnes of capelin are allowed to spawn* (unofficial translation from the Norwegian protocol text).

Recruitment for different cohorts including the 1989 cohort as function of spawning stock biomass is shown in Fig. 1. In the present manuscript, we revise the basis for Blim through a re-estimation of the 1988 maturing stock biomass and a following stock prediction with uncertainty to spring 1989. We use the 95% upper confidence limit of the forecast to define an upper limit of the spawning stock biomass for the given year. In this WD the method is applied to the 1989 cohort since this is presently used as basis for Blim, but the method can be applied to other years with good recruitment from relatively low spawning stock biomasses, for instance 2006 (high herring year), 2020 and 1990 (medium herring years).

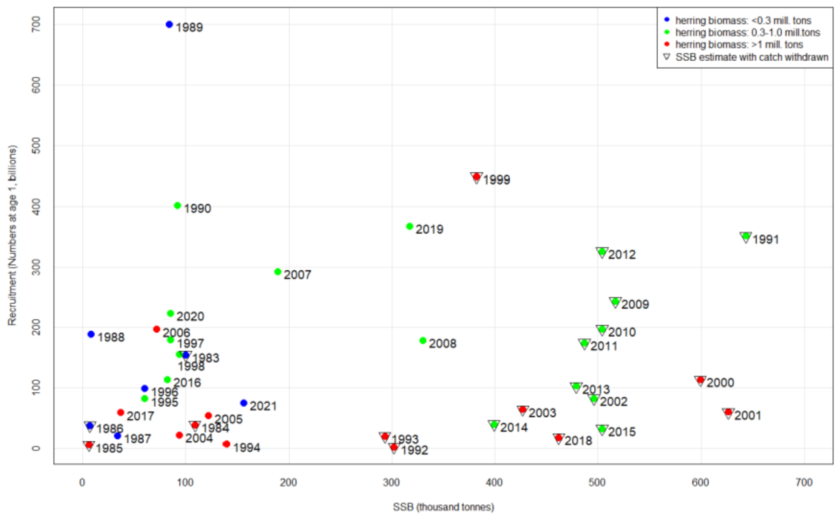

Fig. 1. BS capelin recruitment (abundance at age 1) as a function of spawning stock biomass (SSB). SSB are estimates from the stock forecast model (median values). The years denote cohorts and different colors indicate biomass of young herring (age 1 and age 2) in the Barents Sea. Triangle marks year with catch, so catch is withdrawn in the estimation of the spawning stock biomass.

Data and methods

The acoustic reports from the 1988 survey were available from the Norwegian vessels but not the Russian. However, the covered area was similar for Norwegian and Russian vessels (Fig. 2), so we only expect this to influence the sampling variance associated with the abundance estimate. Biological data were available from the vessels from both countries.

We re-estimated the biomass of capelin for the autumn 1988 using stox v.2.7 (Fig. 3). The procedure is described in ‘WD Capelin monitoring and biomass estimation in autumn’. No individual weight measurements were available in the 1988 data, only individual volume measurements. Hence, we converted volume to weight in the data using a 1:1 conversion factor.

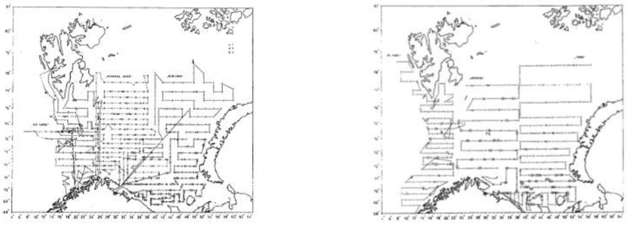

Fig. 2. Survey coverage as displayed in the original survey report. The left panel shows the coverage by the Norwegian vessels 'G.O. Sars', 'Michael Sars' and 'Eldjarn'. The right panel shows the coverage by the Russian vessels 'Prof. Marti', 'Artemida' and 'PINRO'. Acoustic data were available only from the Norwegian vessels, while biological data were available from all vessels.

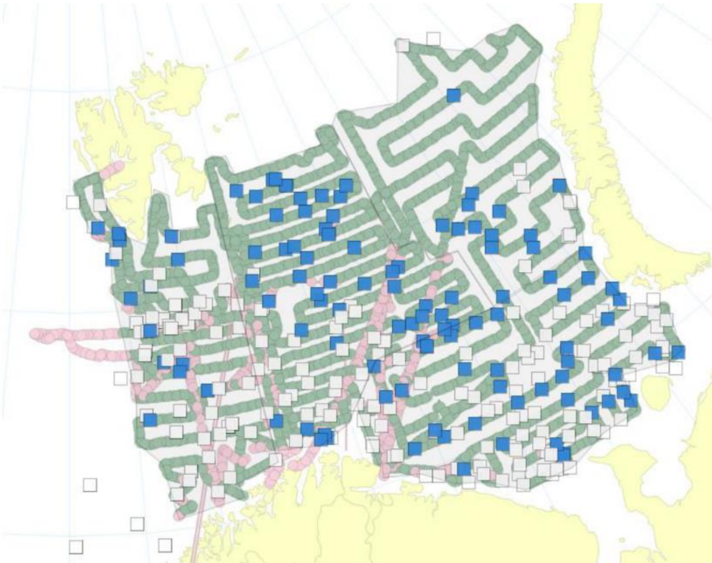

Fig. 3. Screenshot of tagging and stations included in the stox project used for the re-estimation. Defined transects (green) and stations with capelin (blue) and without capelin (white).

Results

The distribution of capelin recorded acoustically is shown in figure 4. Capelin was recorded in a few patches in the central Barents Sea.

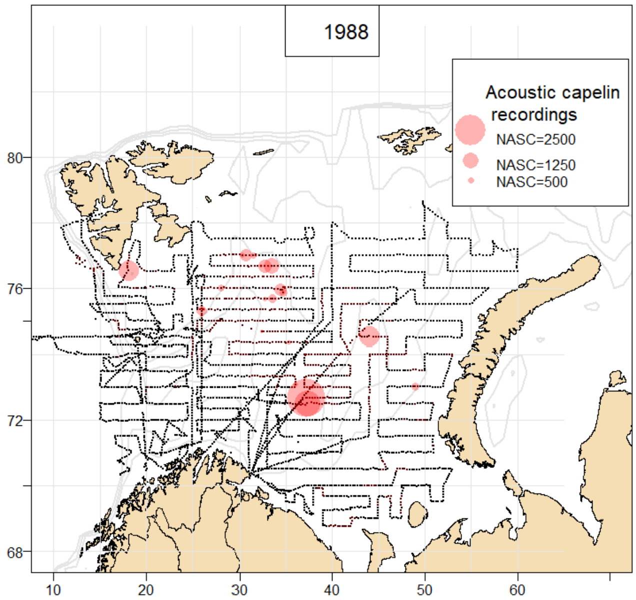

Fig. 4. Acoustic recordings allocated to capelin during the 1988 survey.

The stox estimate of total capelin biomass was at ca. 380 000 tons (Table 1), about 12% below the original estimate and maturing biomass was at ca. 194 000 tons. The 2-year-olds dominate in both biomass and numbers.

Table 1. Output from the stox re-estimation of the 1988 survey data with equal weighting of length distributions from a given station.

Length (cm)	Age 1	Age 2	Age 3	Age 4	Age 5	N (10^9)	BM (10^3 t)	Mean weight (g)
6-7	3.101					3.101	3.068	0.990
7-8	1.077					1.077	1.139	1.060
8-9	3.616					3.616	7.539	2.080
9-10	4.597	0.017				4.614	14.317	3.100
10-11	3.956	0.293				4.248	18.213	4.290
11-12	2.647	2.168				4.814	29.407	6.110
12-13	0.187	4.979				5.166	42.462	8.220
13-14		6.443	0.027			6.470	70.450	10.890
14-15		6.326	0.008			6.334	91.183	14.390
15-16		3.067	0.083			3.150	59.147	18.780
16-17		1.434	0.027			1.461	34.044	23.300
17-18		0.325				0.325	8.881	27.310
18-19		0.017				0.017	0.544	31.270
19-20			0.002			0.002	0.066	42.960
TSN(10^9)	19.180	25.068	0.147			44.396		
TSB(10^3 t)	59.808	317.875	2.711				380.459	
Mean length (cm)	9.520	13.550	15.070					
Mean weight (g)	3.540	12.680	18.600					8.570
MSN 10^9	0.000	11.169	0.120	0.000	0.000			
MSB 10^3 t	0.000	191.455	2.383	0.000	0.000		193.864	

The results from the forecast of maturing capelin is shown in Fig. 5. The 95% confidence limit of the forecast is at 141 000 tons. A scenario with estimated CV from the survey was run with minimal effects on the forecast (CV of abundance of 2-year-olds was estimated at 0.2). A scenario using a fixed fraction of immature cod in the Svalbard area as estimated for 1989 was also tried with minimal impact on the end result.

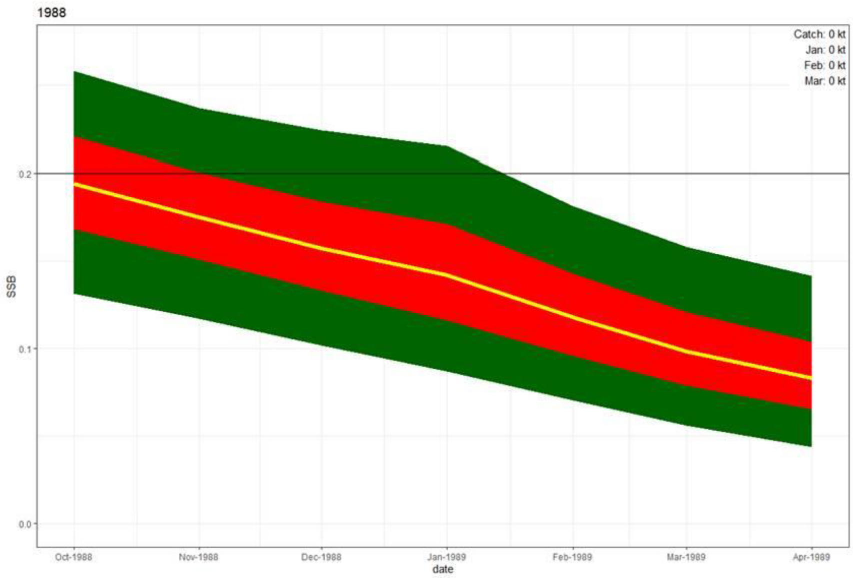

Fig. 5. Forecast of the maturing capelin stock from 1 October 1988 to 1 April 1989. In the forecast, the updated capelin estimate is used and updated cod abundance. A fixed CV of 0.2 by age group is used. The consumption parameters are taken from the consumption model presently used in the assessment, and the fraction of immature cod in the Svalbard area is the same as used in the assessment. The M in the autumn is drawn from the same distribution as is used presently in the assessment (see WD_BS6).

Work conducted during the benchmark meeting

The sections prior to the present were contained in the original WD presented for the benchmark meeting. There was an error in Figure 1 which has been corrected, and the figure is replaced.

The addition in the following were presented during the meeting on request. Figure 6 shows the abundance at age 2 as a function of estimated spawning stock biomass. The figure confirms that 1989 was an outlier in the time series. Figure 7 shows the number of recruits (age 1) as a function of estimated spawning stock biomass, with a fit from a segmented regression analysis (R-package *segmented*). The low herring years prior to 1990 have been removed from the comparison. The NSS herring stock collapsed during the 1960s and the period until recovery must be considered abnormal in the southern Barents Sea ecosystem given the ecological importance of NSS herring. The estimates associated with the abnormal survey year 2016 have also also removed. The estimated breakpoint is at 72000 tons with a standard error of 46000 tons.

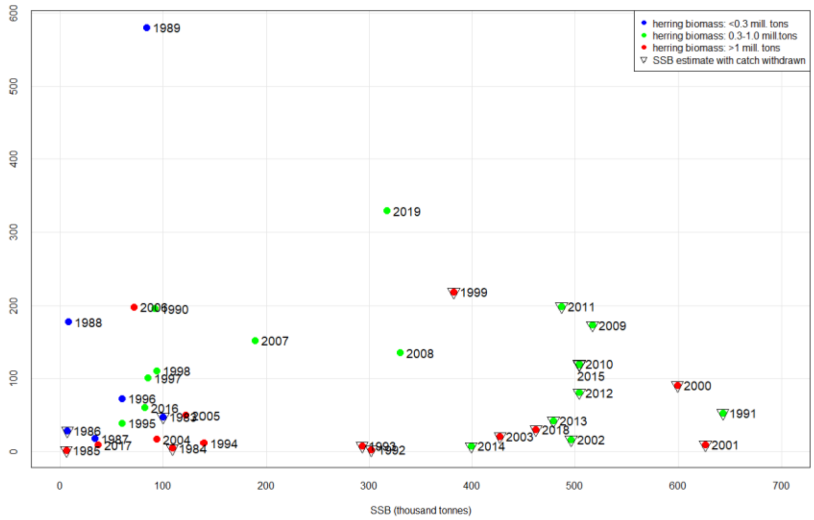

Fig. 6. BS capelin abundance at age 2 as a function of estimated spawning stock biomass (SSB). SSB are estimates from the stock forecast model (median values). The years denote cohorts and different colors indicate biomass of young herring (age 1 and age 2) in the Barents Sea. Triangle marks year with catch, so catch is withdrawn in the estimation of the spawning stock biomass. Note that the dots for the years 2010 and 2015 are almost in identical position and not separable in the plot.

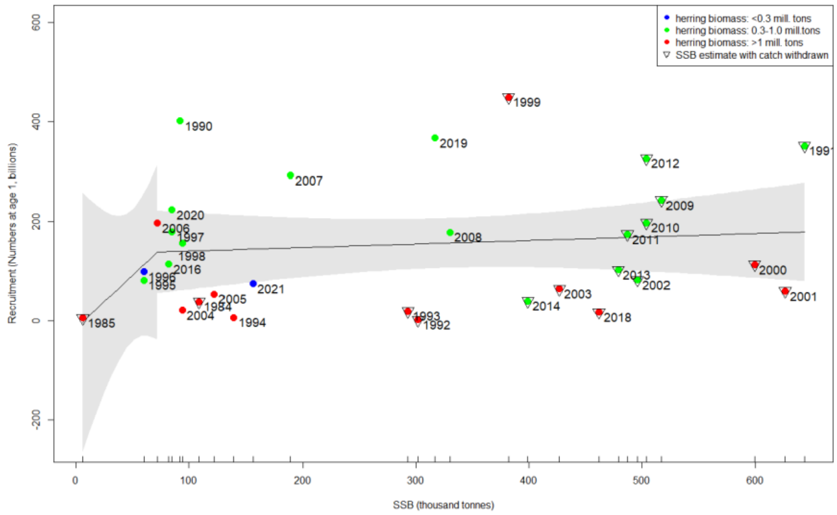

Fig. 7. Results from Segmented regression analysis fitted to the SSB-Recruitment data. BS capelin recruitment (abundance at age 1) as a function of spawning stock biomass (SSB). SSB are estimates from the stock forecast model (median values). The years denote cohorts and different colors indicate biomass of young herring (age 1 and age 2) in the Barents Sea. Triangle marks year with catch, so catch is withdrawn in the estimation of the spawning stock biomass.

Reference

Gjøsæter H, Bogstad B, Tjelmeland S (2002) Assessment methodology for Barents Sea capelin, *Mallotus villosus* (Müller). ICES J Mar Sci 59:1086-1095

WD_BS9 Maturation model for Barents Sea capelin

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WD BS9, WKCAPELIN, Reykjavik 21-25 November 2022

Present model

The maturation model presently used in the capelin assessment is:

$$m(l) = \frac{1}{1 + e^{4*P1*(P2-l)}}$$

where *m(l)* is the proportion of mature fish at length *l* and P1 and P2 are parameters to be estimated.

The values of P1 and P2 presently used are P1=3.5 (fixed) and P2=13.89 (variable, SD=0.075, calculated using 1000 replicates).

These values were estimated based on data from the period 1972-1980 (ICES, 2009), where the stock situation was relatively stable, growth was slower than today and the contribution of age 4 fish to the maturing stock was not negligible. They are close to the values estimated by Tjelmeland and Bogstad (1993), where P1 was fixed to 0.6 and P2 was estimated separately for females and males to 13.65 and 14.04 cm, respectively, using data from 1972-1990. Those parameters were estimated by comparing the length distribution of fish age 3, 4 and 5 simulated by starting the model in the previous autumn, to corresponding mean values.

It should also be noted that there is an inconsistency in the reporting of mature stock in the assessment at present, as the values above are used in the prediction model used to give quota advice, while a cut-off of 14.0 cm is used to calculate the historic values of maturing stock. This causes a slight discrepancy in the biomass of the maturing stock in the current year reported in the assessment and advice sheet (e.g. for the 2022 assessment the median maturing biomass in 2022 with no correction for incomplete area coverage is 833 kt with the proportion mature calculated using replicates based on values of P1 and P2 given above vs. 817 kt with a cut-off of 14.0 cm).

Auxiliary data giving information about maturation

We assume no length growth in the period from 1 October to 1 April. There are three data sources that provide information about length distribution of capelin caught or eaten in winter:

- Fisheries
- Spawning survey
- Cod stomach data

The fisheries and the spawning survey take place relatively close to the coast and after the maturing capelin have started migrating to the spawning areas and have separated from the immature capelin. The cod stomach data are sampled over a much wider area and the sampling starts in January, thus one would expect that the proportion of immature capelin is larger in the cod stomachs than in the two other data sources. Fig 1-3 shows the length distributions in fisheries, spawning survey and cod stomachs, respectively.

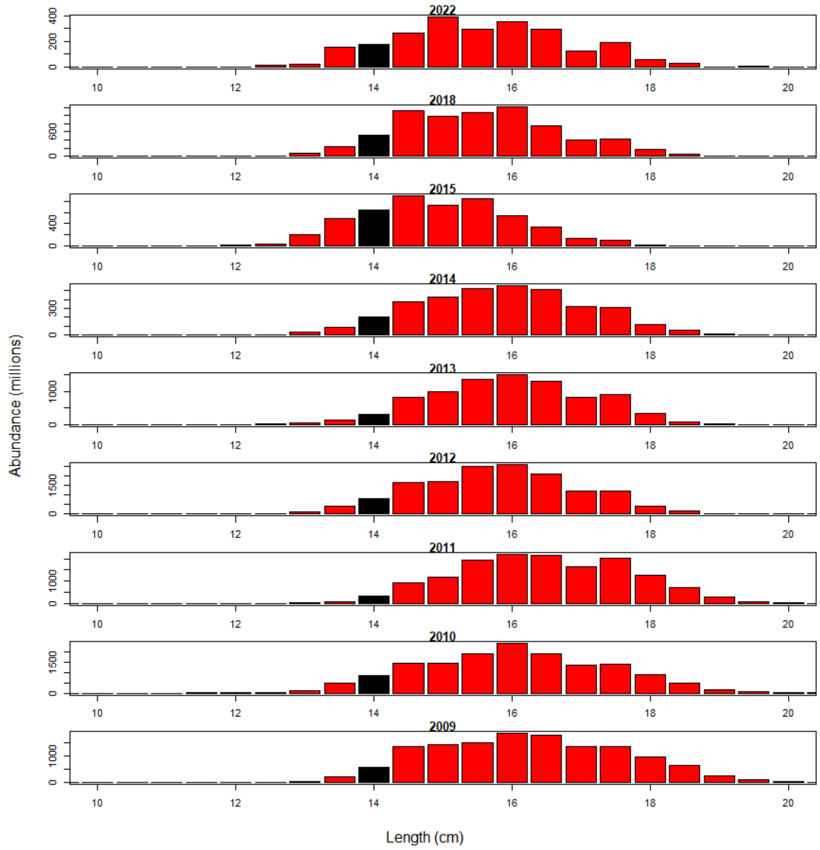


Fig. 1. *Length distribution of BS capelin based on fisheries data. Note that for the years 2004-2008, 2016-2017 and 2019-2021 there was no fishery.*

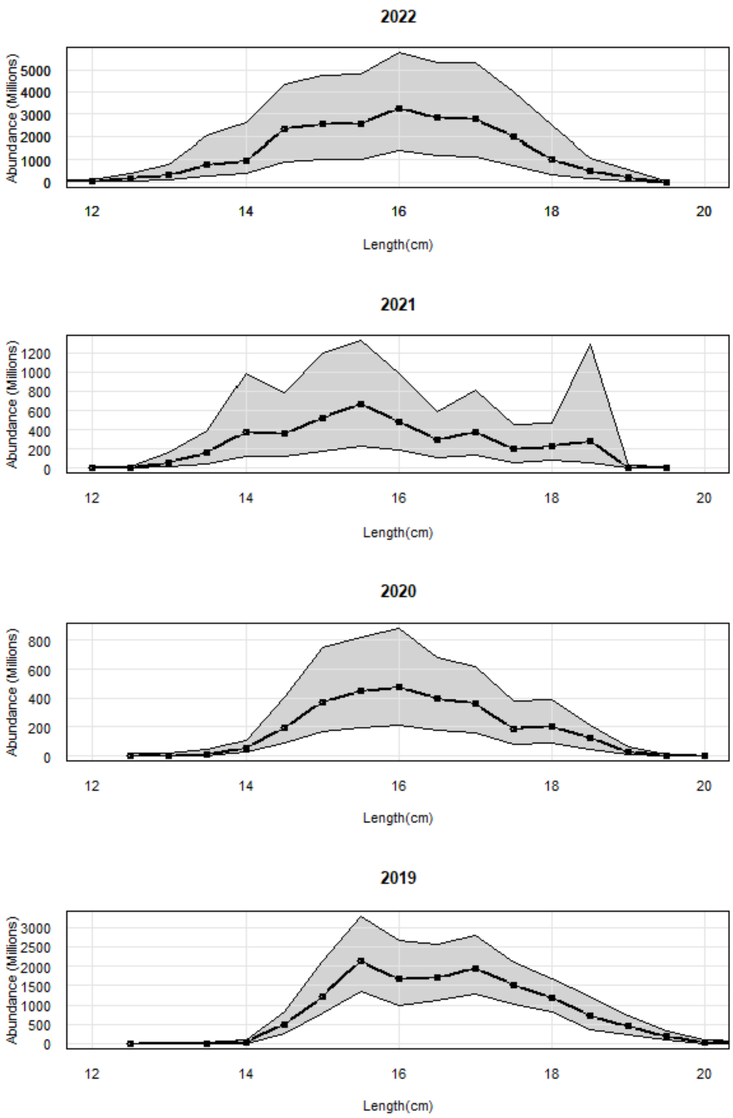


Fig. 2. *Length distribution in spawning survey 2019-2022*

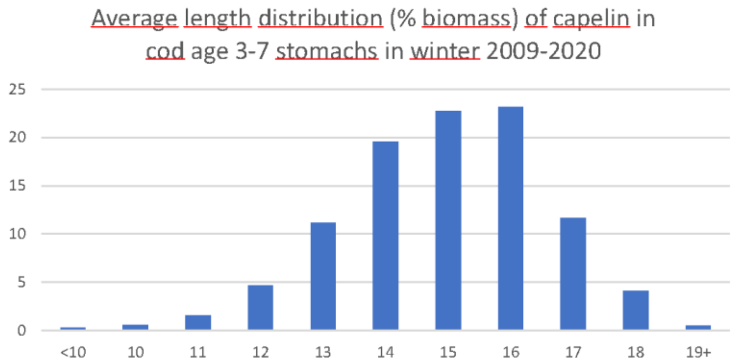


Fig. 3. *Average length distribution (% biomass) of capelin in cod age 3-7 stomachs from winter survey 2009-2020, only from cod caught south of 74° N.*

Sensitivity to maturation length

In order to show the sensitivity of the maturing biomass to the maturation model, we have calculated the maturing biomass for cut-off lengths of 13.0, 13.5, 14.0, 14.5 and 15.0 cm, as well as for the currently used maturation function. The results are shown in Fig. 4.

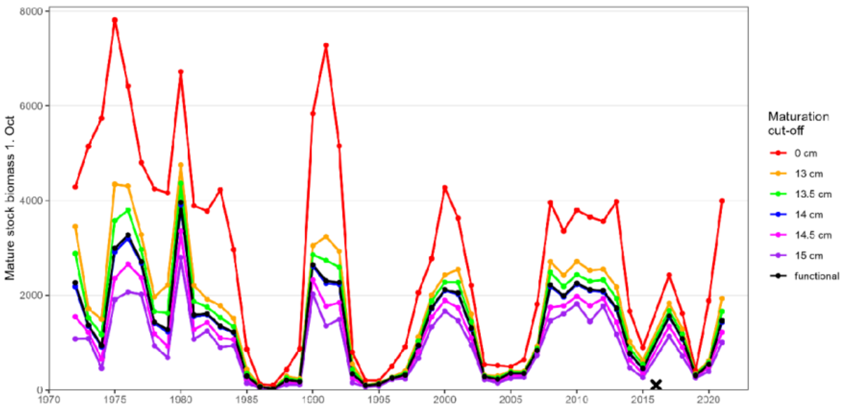


Fig 4. *Maturing biomass from survey for different cut-off lengths as well as for the maturation function presently used ('functional'). Also the total biomass ('cut-off 0 cm') is shown.*

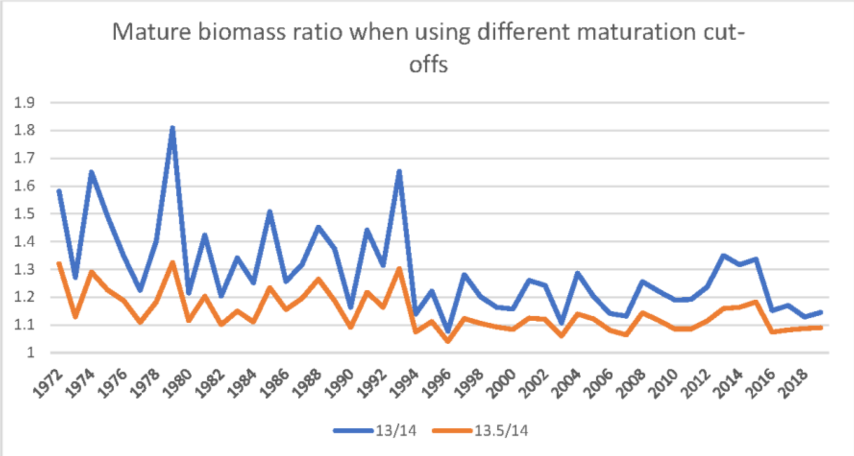


Fig.5. *Ratio of maturing biomass for cut-off maturation lengths of 13.5 and 13.0 cm compared to reference length of 14.0 cm.*

Fig. 5 shows how much the mature biomass changes when decreasing the cut-off maturation length from 14.0 to 13.5 or 13.0 cm. From the mid-1990s onwards these ratios are relatively stable (1.1 and 1.2 respectively), while in earlier years they are higher and more variable.

Re-estimation of parameters

We tried to re-estimate the maturation parameters for the recent time period (1990-1991 to 2020-2021) taking the same approach as Tjelmeland and Bogstad (1993), but without taking sex differences into account and comparing only survey data of number of age 2 immature in one year with total number of age 3 in the following year. When assuming maturation to be constant over time, annual mortalities can be estimated. The survey in 2016 is considered to be a considerable underestimate and is not included in the estimations, meaning that mortalities from 2015-2016 and 2016-2017 are not included. Such estimations are ongoing.

Is maturation constant over time? Some previous studies

Baulier et al. (2012) considered temporal stability of the maturation of Barents Sea capelin. They applied the probabilistic maturation reaction norm (PMRN) method to test this assumption and to detect possible temporal changes in length at maturation of Barents Sea capelin between 1978 and 2008. Maturation reaction norms suggest that maturation is age-independent in capelin, but that males require a larger size to attain the same maturation probability as females. No temporal trends in length at maturation could be detected, thus confirming the theoretical prediction. Furthermore, none of the candidate environmental variables tested to explain the temporal variability in length at maturation (water temperature and capelin biomass) consistently showed a significant correlation with the PMRN midpoints.

Different results were obtained by Jokar et al. (2021) who found that maturation parameters varied considerably over time, and that maturation intensity is higher at low stock size. The high annual variability in maturation length and also their maturation curve for years with fisheries (figs 3 and 9, respectively) in that paper does, however, show maturation lengths which are not consistent with the relatively stable length composition in catches and spawning surveys shown in Fig. 1-2 in this WD.

Jourdain et al. (2021) contrasted length- and gonad-based metrics for maturation of Barents Sea capelin and found that maturity-at-length estimates (using 14 cm as maturation length) usually exceed gonad-based estimates. It should be noted, however, that in this analysis only data for age 2 fish from planned pelagic stations (0-group hauls) were used, which may have a notable effect on the results as the fish found in these hauls is generally smaller and younger than fish caught in registration and bottom trawl hauls.

Work conducted during the benchmark meeting

The sections prior to the present were contained in the original WD presented for the benchmark meeting.

The additions in the following were presented during the meeting on request. Figure 6 shows a comparison of estimated maturing biomass over the time series using P1 of 0.6 and 3.5, respectively, and a fixed P2 of 13.89 cm. These two values of P1 are found in the literature and used historically. The proportion of maturing fish *m* by length group *l* is defined by:

$$m_l = m_l(p_1, p_2) = \frac{1}{1+\exp\left(4p_1(p_2-l)\right)}$$

In figure 7, the resulting maturing proportion by length group using the two different values of P1 (0.6 and 3.5), are compared to the length distributions from the catch for the years after 2003 with catches.

Figure 8 shows the slopes resulting from the maturity estimation which is described in BS10 (in the Appendix). The results of the estimation are validated by plotting autumn survey data in year y versus spawning survey data in spring year y+1. These results are shown in Figure 9.

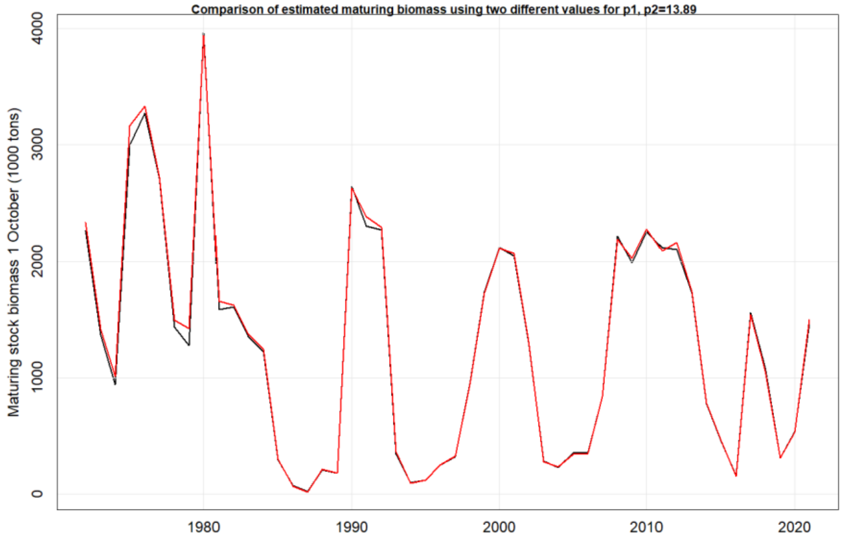
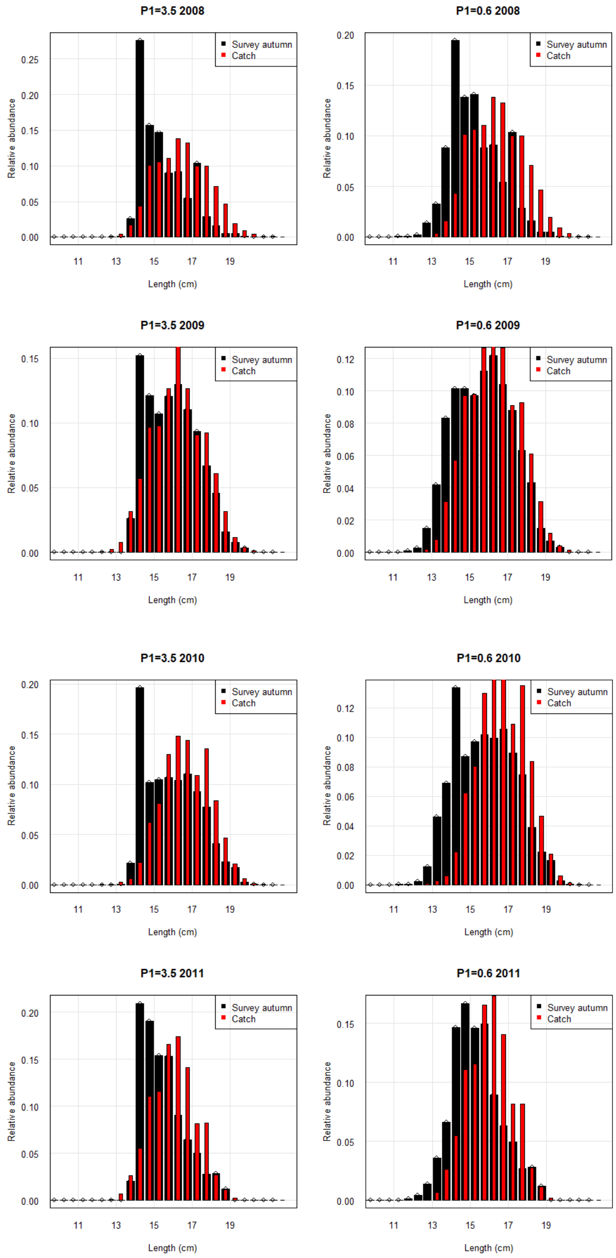
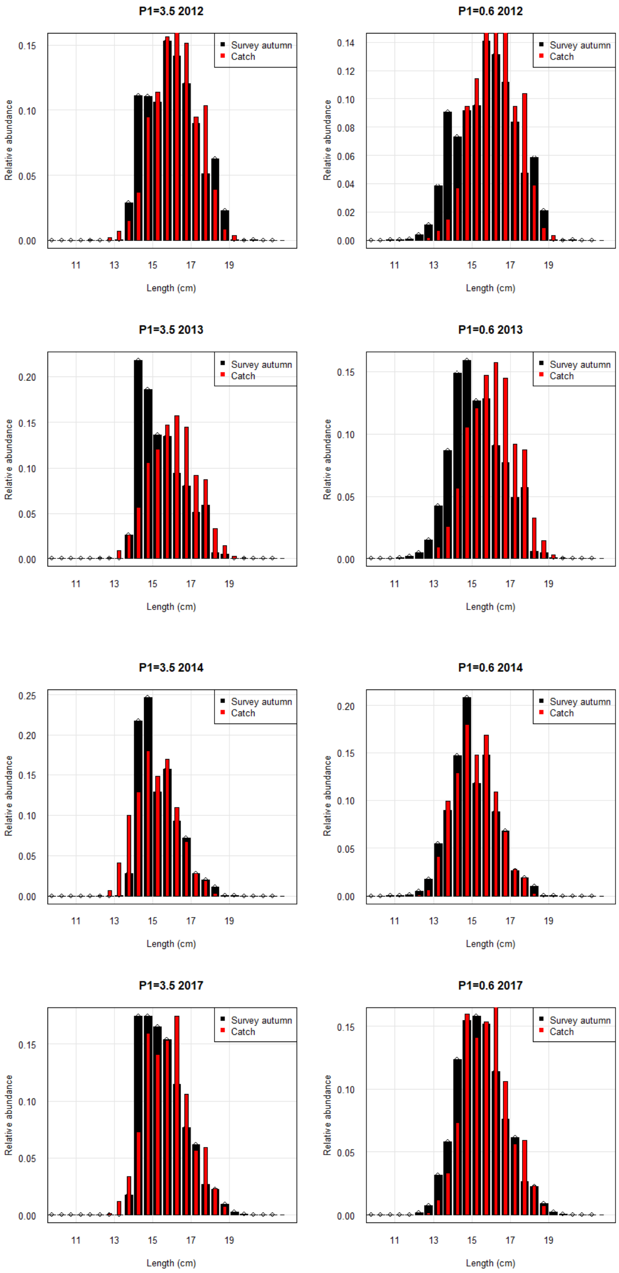


Fig. 6. Comparison of estimated maturing capelin biomass using a value of 0.6 for P1 (shallow slope) and 3.5 (steep slope). P2 is kept fixed at 13.89 cm.


P1=3.5 2008
P1=0.6 2008
P1=3.5 2009
P1=0.6 2009
P1=3.5 2010
P1=0.6 2010
P1=3.5 2011
P1=0.6 2011
Survey autumn
Catch
Relative abundance
Length (cm)


P1=3.5 2012
P1=0.6 2012
P1=3.5 2013
P1=0.6 2013
P1=3.5 2014
P1=0.6 2014
P1=3.5 2017
P1=0.6 2017
Survey autumn
Catch
Relative abundance
Length (cm)

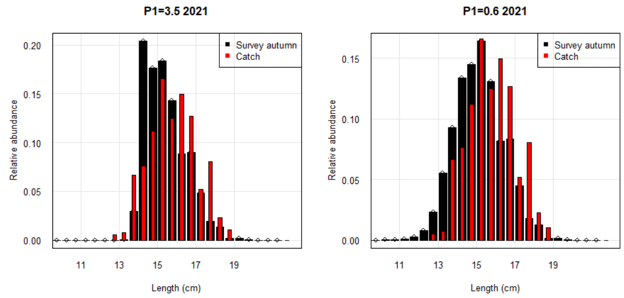


Fig. 7. Comparison of length distribution from the autumn survey (black), and catches (red) setting p1 to 3.5 (steep slope, left side panels), and setting p1 to 0.6 (shallower slope, right side panels).

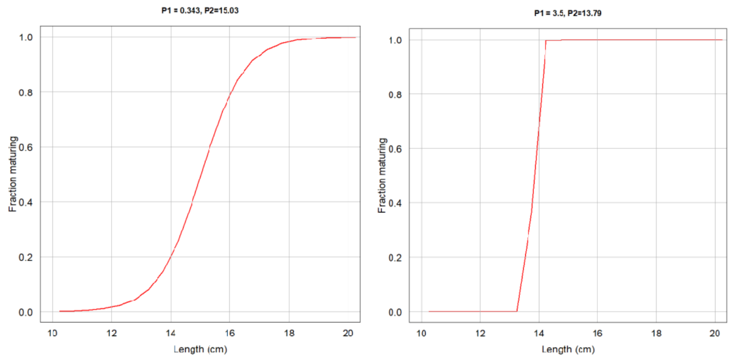


Fig. 8. Slopes resulting from: estimating P1 and P2 (left panel), and estimating P2 while keeping P1 fixed at 3.5 (right panel). Estimation is done minimizing likelihood function (2) and comparing against length distribution from the catches.

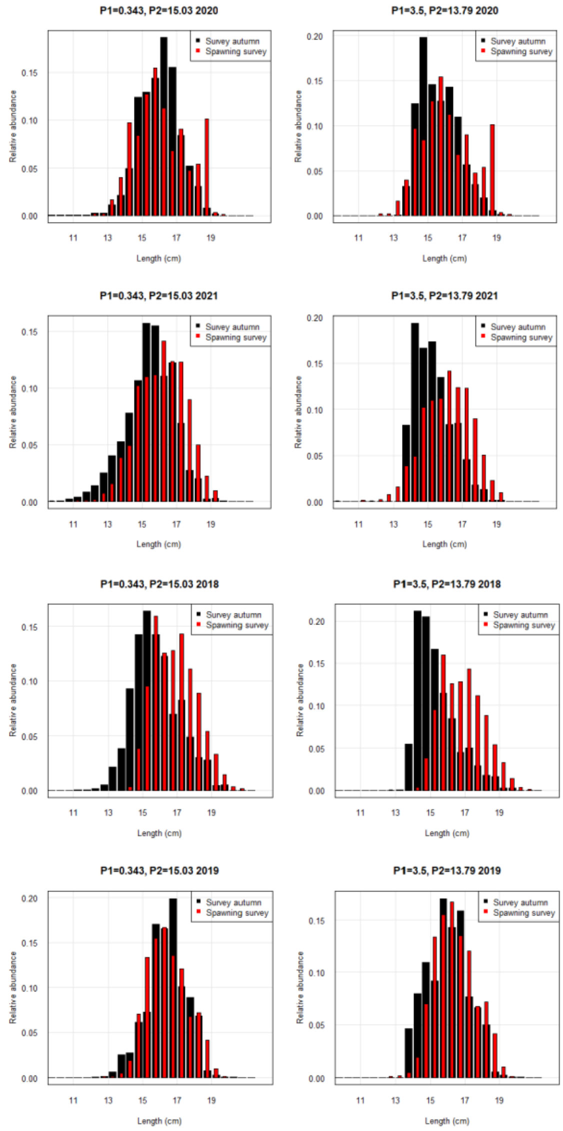


Fig. 9. Validation of maturity estimates based on catch data described in BS10. The figures show comparisons of length distribution from the autumn survey (black), and spawning survey the following spring (red) with parameters resulting from estimation exercise 1 (both P1 and P2 estimated; P1=0.343, P2=15.03) and estimation exercise 2 (P1 is fixed at 3.5, P2 is estimated to 13.79).

References

Baulier, L., Heino, M. and Gjøsæter, H., 2012. Temporal stability of the maturation schedule of capelin Mallotus villosus in the Barents Sea. Aquat. Living Resour. 25, 151–161. https://doi.org/10.1051/alr/2012014.

ICES. 2009. Report of the Benchmark Workshop on Short-lived Species (WKSHORT). 34. 166 pp.

Jokar, M., Subbey, S., and Gjøsæter, H. 2021. A logistic function to track time-dependent fish population dynamics. Fisheries Research 236: 105840.

Jourdain, N. O. A. S., Fuglebakk, E., and Subbey, S. 2021. Maturation in the Barents Sea capelin – contrasting length- and gonad-based metrics. Fisheries Research 237: 105880.

Tjelmeland, S., and Bogstad, B. 1993. The Barents Sea capelin stock collapse: A lesson to learn. In S. J. Smith, J. J. Hunt and D. Rivard (ed.). Risk Evaluation and Biological Reference Points for Fisheries Management. Can. Spec. Publ. Fish. Aq. Sci. 120: 127-139.

Maturation using catch data

Sondre Hølleland

2022-11-23

We start by loading the data and structuring them such that we have numbers per length from either survey data from year y or catch data the following year $y + 1$.

```
library(tidyverse)
library(bifrost)
survey  <- read_csv("../Table for Sondre.csv")
catches <- read_csv("../Catch for Sondre.csv")

# -- add up all ages--
survey <- survey %>% mutate(
  Nsurvey =  rowSums(across(c(age1,age2,age3,age4)), na.rm=T)
)
catches <- catches %>% mutate(
  Ncatch = rowSums(across(c(N1,N2,N3,N4)), na.rm=T)
)

# join the two datasets
dat <- left_join(catches %>%
                   rename(meanlength = Length_group)%>%
                   select(Ncatch,year, meanlength),
          survey %>%
            select(Nsurvey,year, meanlength),
          by = c("year","meanlength"))  %>%
  filter(year <2022)
# There are some NAs in the survey data
# (these are all very long fish with zero in the catches as well)
dat$Nsurvey[is.na(dat$Nsurvey)] <- 0

# We standardize the catches by yearly totals:
dat <- dat %>%
  group_by(year) %>%
  mutate(Nc = Ncatch/sum(Ncatch)) %>%
  ungroup()
```

So then we have the data on the following form (removing the smallest fish from the print out):

```
dat %>% filter(meanlength > 14)
```

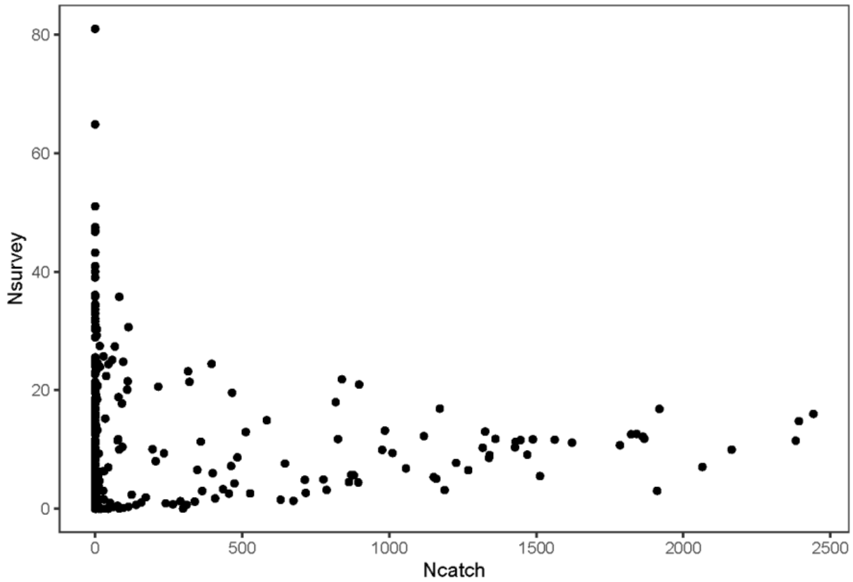
```
## # A tibble: 176 x 5
##    Ncatch  year meanlength Nsurvey      Nc
##     <dbl> <dbl>      <dbl>   <dbl>   <dbl>
##  1   8.69  2005       14.2    3.73   0.143
##  2  11.6   2005       14.8    3.77   0.190
##  3   8.41  2005       15.2    3.85   0.138
```

```
## 4  8.07   2005       15.8  3.14   0.133
## 5  8.33   2005       16.2  1.54   0.137
## 6  4.72   2005       16.8  0.875  0.0775
## 7  0.795  2005       17.2  1.80   0.0131
## 8  0.559  2005       17.8  0.174  0.00919
## 9  0.248  2005       18.2  0.0612 0.00408
## 10 0      2005       18.8  0      0
## # ... with 166 more rows
```

For each year, we have number of fish in the survey and in the catches the following year. The Nc column is the relative number of fish in each length group relative to the total.

We can plot the two data columns against eachother:

```
dat %>% ggplot(aes(x=Ncatch, y = Nsurvey)) + geom_point()
```



The goal is now to find the maturity function that will make the number of mature fish in the survey the closest to the have the same relative distribution as we see in the catches. For notational purposes, let N_ℓ^S be the number of fish in the length group ℓ from the survey and N_ℓ^C the corresponding for the standardized Nc column. We have that the proportion of mature fish in length group ℓ is

$$m_\ell = m_\ell(p_1, p_2) = \frac{1}{1 + \exp(4p_1(p_2 - \ell))}.$$

We will thus have to find the $p = (p_1, p_2)$, that minimizes

$$Q(p) = \sum_\ell \left(\frac{m_\ell N_\ell^S}{\sum_k m_k N_k^S} - N_\ell^C \right)^2.$$

For simplicity we have not included the year in the notation above, but we treat the years separately and sum up the sum of squared differences. Thus, we define the following function:

```
obj <- function(p,dat){
  MAT <- sapply(dat$meanlength,
                FUN = bifrost::maturing,
                p1  = p[1],
                p2  = p[2])
  matNs <- dat %>%
    mutate(matNs = MAT*Nsurvey) %>%
    group_by(year) %>%
    mutate(
      matNs =( matNs)/sum(matNs)) %>% pull(matNs)
  sum((matNs-dat$Nc)^2)
}
```

We can then minimize the function:

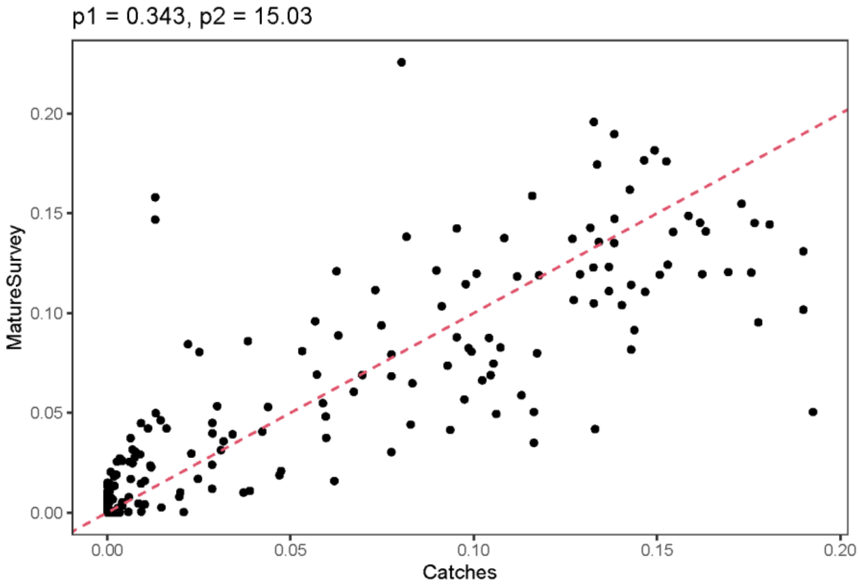
```
opt <- nlminb(start = c(3.5,13.89), objective = obj,
       dat = dat)
opt
```

```
## $par
## [1]  0.3433239 15.0256269
##
## $objective
## [1] 0.2249956
##
## $convergence
## [1] 0
##
## $iterations
## [1] 19
##
## $evaluations
## function gradient
##       28       45
##
## $message
## [1] "relative convergence (4)"
```

As you can see, $p1 = 0.343$ and $p_2 = 15.03$. To visualize the fit, we can redo the plot above, but now we multiply the Nsurvey with the mature porportion:

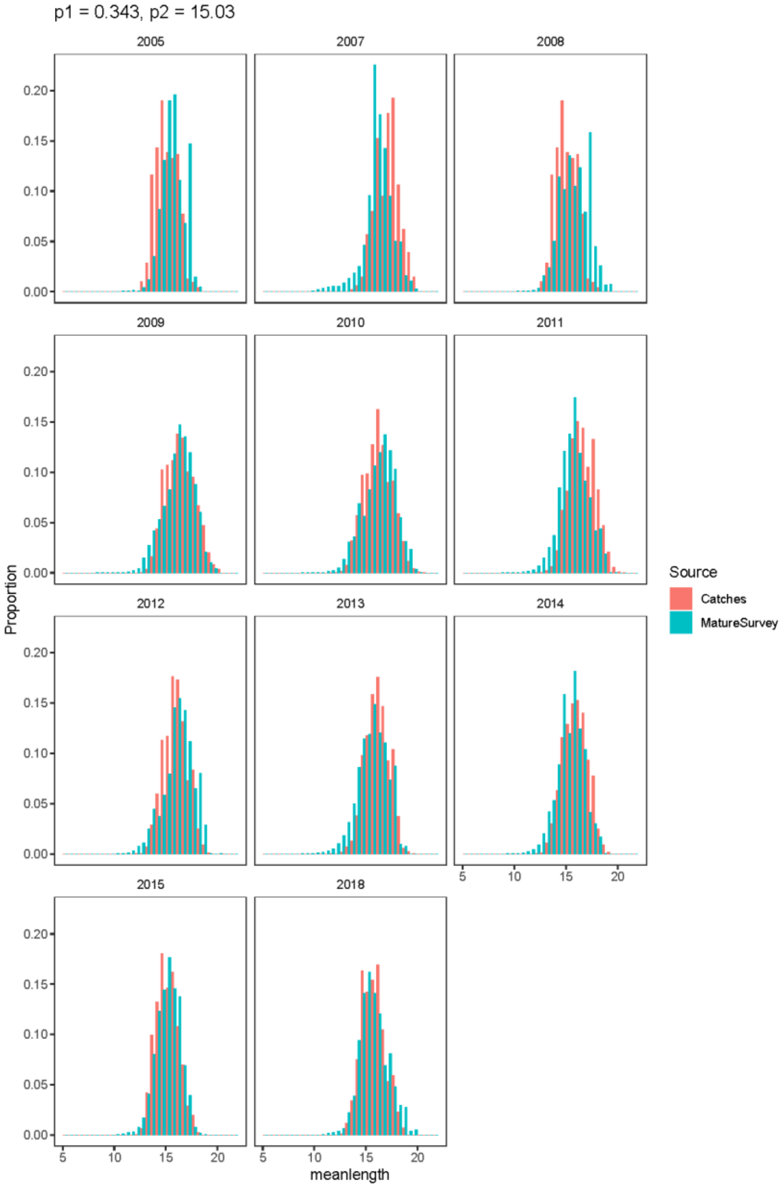
```
dat.mature <- dat %>%
  mutate(
    mat= bifrost::maturing(meanlength,
                           p1=opt$par[1],
                           p2=opt$par[2]),
    matS = mat*Nsurvey
  ) %>%
  group_by(year) %>%
  mutate(MatureSurvey =matS/sum(matS)) %>%
  rename(Catches = Nc) %>%
  ungroup()
```

```
dat.mature %>%
  ggplot(aes(x=Catches, y = MatureSurvey)) +
  geom_point()+
  geom_abline(slope = 1, intercept = 0, col = 2, lty = 2)+
  labs(title = "p1 = 0.343, p2 = 15.03")
```



We can also plot the results by length as bar plots for each of the years:

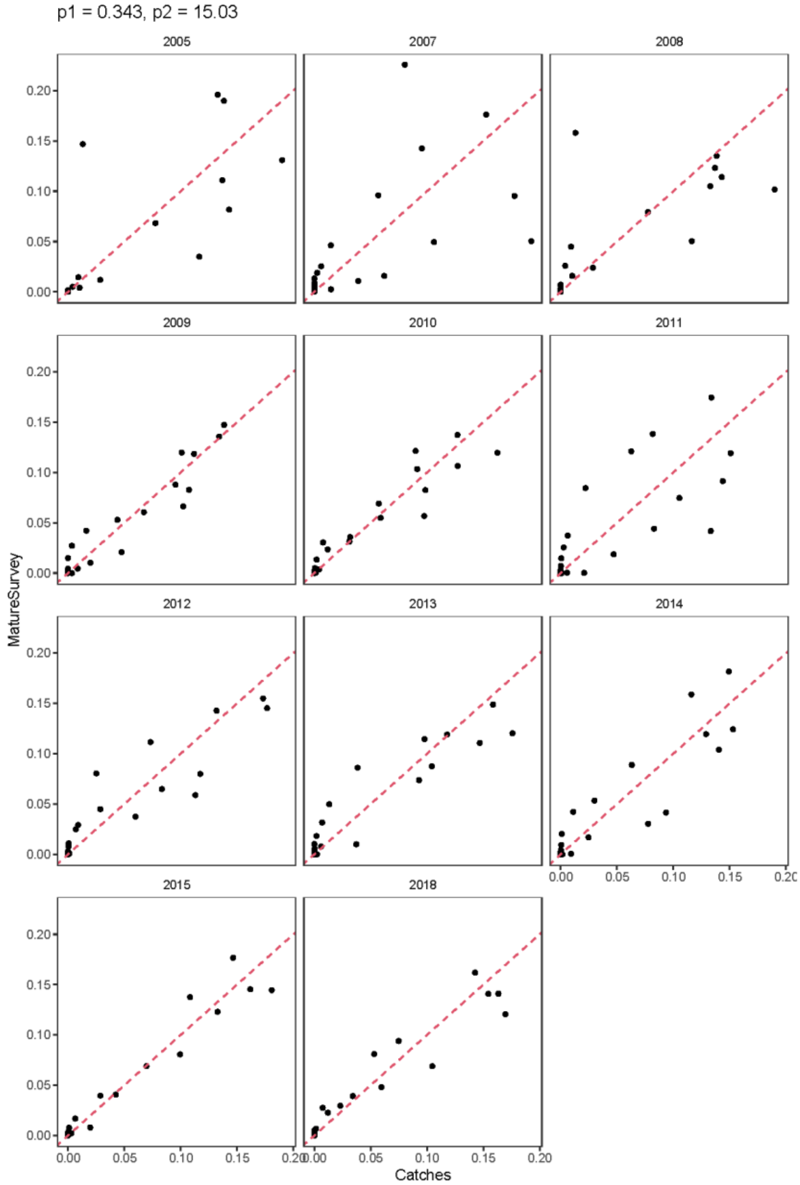
```
dat.mature %>%
  pivot_longer(cols = c(Catches,MatureSurvey),
               names_to = "Source",
               values_to = "Proportion") %>%
ggplot(aes(x     = meanlength,
           y     = Proportion,
           fill = Source)) +
  geom_bar(stat="identity", position = "dodge") +
  facet_wrap( ~year, ncol = 3)+
  labs(title = "p1 = 0.343, p2 = 15.03")
```


p1 = 0.343, p2 = 15.03
2005
2007
2008
2009
2010
2011
2012
2013
2014
2015
2018
Proportion
meanlength
Source
Catches
MatureSurvey

5

We can make scatter plots by year with the porportions in the catches against the proportions in the fitting mature survey population:

```
dat.mature %>%
ggplot(aes(x     = Catches,
           y     = MatureSurvey)) +
  geom_point()+
  facet_wrap( ~year, ncol = 3)+
  geom_abline(slope = 1, intercept = 0, col = 2, lty = 2)+
  labs(title = "p1 = 0.343, p2 = 15.03")
```


p1 = 0.343, p2 = 15.03
2005
2007
2008
2009
2010
2011
2012
2013
2014
2015
2018
MatureSurvey
Catches
0.00
0.05
0.10
0.15
0.20

Fixing $p_1 = 3.5$

We can also repeat the same exercise, but fix $p_1 = 3.5$.

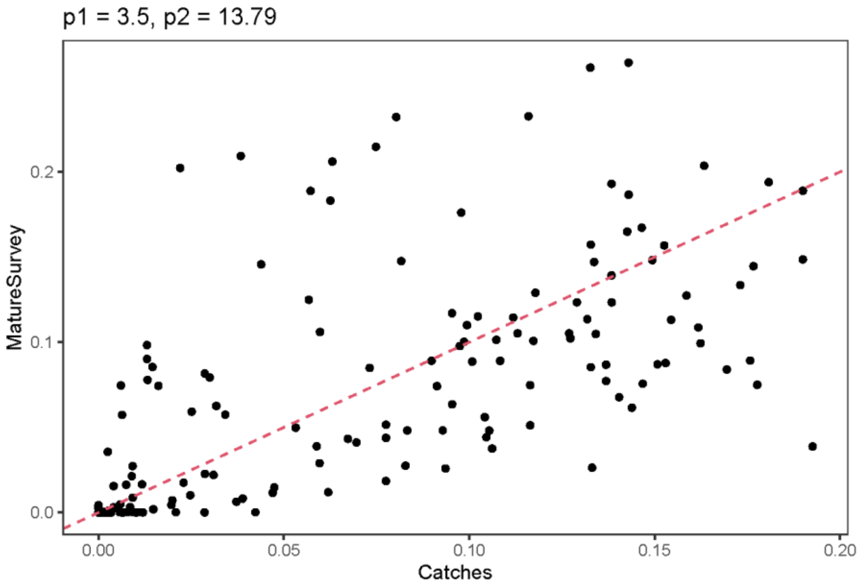
```
obj.fixp1 <- function(p,dat){
  MAT <- sapply(dat$meanlength,
                FUN = bifrost::maturing,
                p1  = 3.5,
                p2  = p[1])
  matNs <- dat %>%
    mutate(matNs = MAT*Nsurvey) %>%
    group_by(year) %>%
    mutate(
      matNs =( matNs)/sum(matNs)) %>% pull(matNs)
  sum((matNs-dat$Nc)^2)
}
opt <- nlminb(start = 13.89, objective = obj.fixp1,
       dat = dat)
opt
```

```
## $par
## [1] 13.78822
##
## $objective
## [1] 0.4452749
##
## $convergence
## [1] 0
##
## $iterations
## [1] 5
##
## $evaluations
## function gradient
##        8        8
##
## $message
## [1] "both X-convergence and relative convergence (5)"
```

So if we fix $p_1 = 3.5$, we get that $p_2 = 13.79$, and the figures above become:

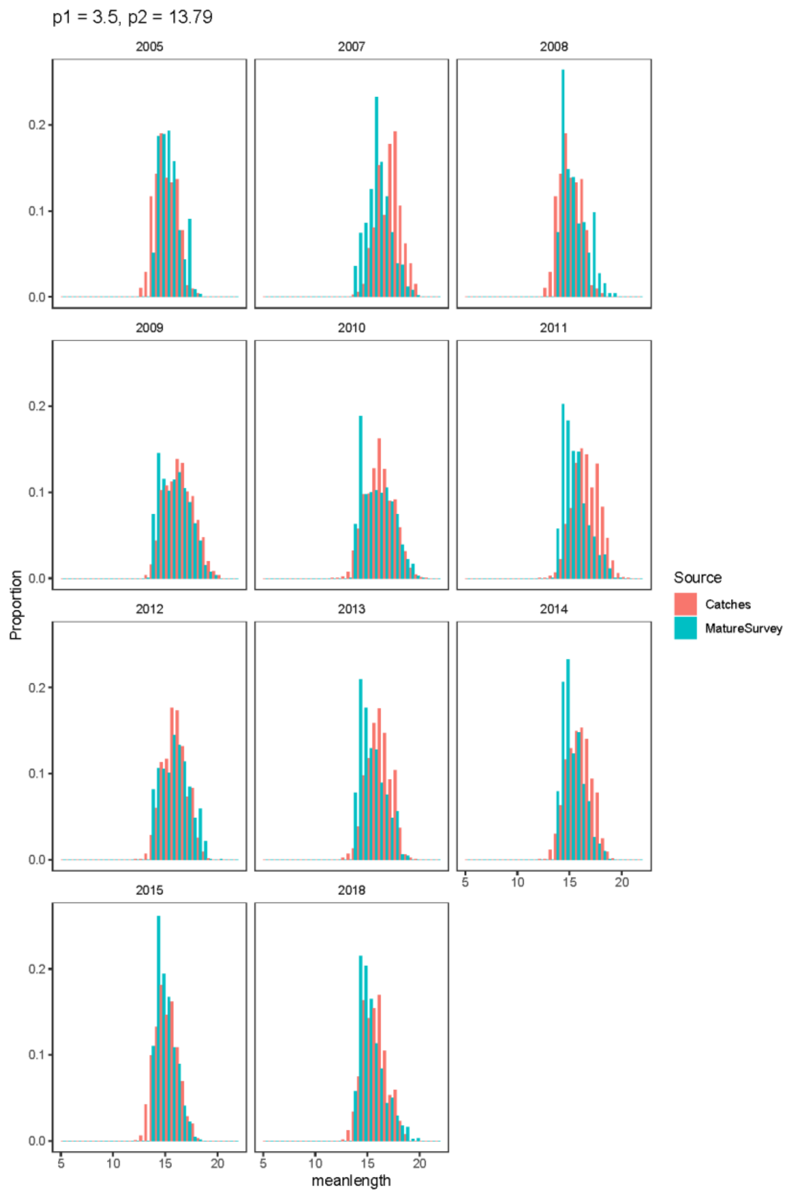
```
dat.p2only <- dat %>%
  mutate(
    mat= bifrost::maturing(meanlength, p1=3.5, p2=opt$par[1]),
    matS = mat*Nsurvey
  ) %>%
  group_by(year) %>%
  mutate(MatureSurvey =matS/sum(matS)) %>%
  rename(Catches = Nc) %>%
  ungroup()

dat.p2only %>%
  ggplot(aes(x=Catches, y = MatureSurvey)) +
  geom_point()+
  geom_abline(slope = 1, intercept = 0, col = 2, lty = 2)+
  labs(title = "p1 = 3.5, p2 = 13.79")
```

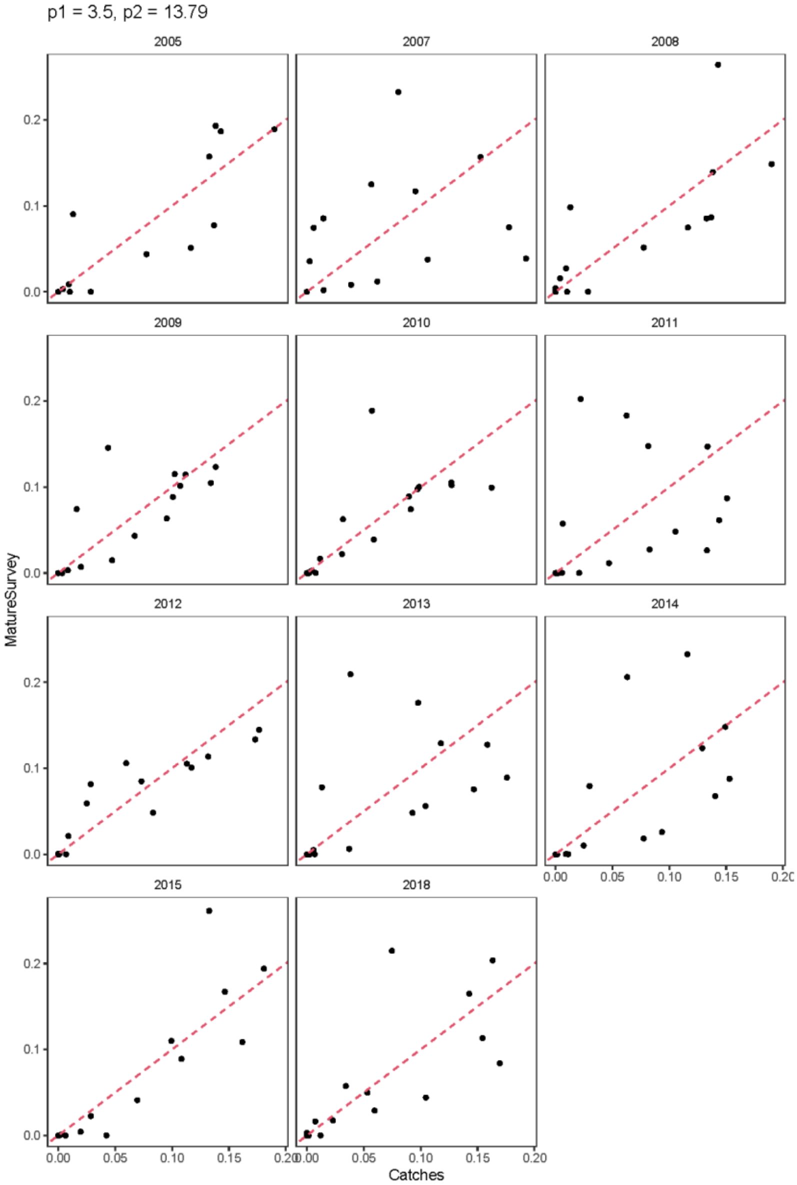


We can also do the similar plotting by year for this scenario:

```
dat.p2only %>%
  pivot_longer(cols = c(Catches,MatureSurvey),
               names_to = "Source",
               values_to = "Proportion") %>%
ggplot(aes(x     = meanlength,
           y     = Proportion,
           fill = Source)) +
  geom_bar(stat="identity", position = "dodge") +
  facet_wrap( ~year, ncol = 3)+
  labs(title = "p1 = 3.5, p2 = 13.79")
```


p1 = 3.5, p2 = 13.79
2005
2007
2008
2009
2010
2011
2012
2013
2014
2015
2018
Proportion
meanlength
Source
Catches
MatureSurvey

```
dat.p2only %>%
ggplot(aes(x     = Catches,
           y     = MatureSurvey)) +
  geom_point()+
  facet_wrap( ~year, ncol = 3)+
  geom_abline(slope = 1, intercept = 0, col = 2, lty = 2)+
  labs(title = "p1 = 3.5, p2 = 13.79")
```



p1 = 3.5, p2 = 13.79
2005
2007
2008
2009
2010
2011
2012
2013
2014
2015
2018
MatureSurvey
Catches
0.0
0.1
0.2
0.00
0.05
0.10
0.15
0.20

Annex 4: IEGJM capelin – Working documents

I01. Capelin data and advisory process. Overview. (I01_Overview.docx)
I02. Cofficient of Variation of Surveys. (I02_CVSurveys.docx)
I03. Description of the predation model. (I03_PredationModel.docx)
I04. Calculations of the spawning stock from 1981–2022, estimation of B_{lim} and advice given by the new HCR from 2015. (I04_HistoricalSSBandBlim.docx)
I05. Re-evaluation of the target strength and the acoustic properties of the capelin stock in the Iceland-East Greenland-Jan Mayen area. (I05_TS_Benchmark.docx)
I06. Capelin fisheries in the Iceland-East Greenland-Jan Mayen area.
I07. IEGJ capelin. Experience with new management plan 2015/16 to 2021/22.

Working Document I01. Capelin data and advice. Overview

1 Use of acoustic measurements in the assessment

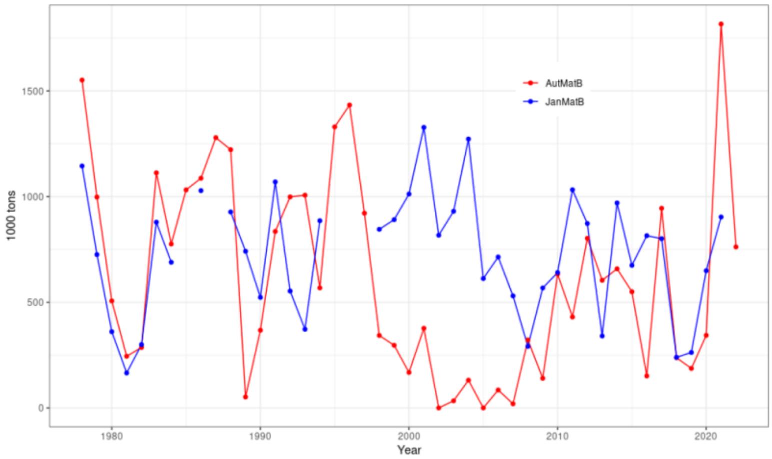


Figure 1.1: Biomass of mature capelin in autumn and winter. The year indicates year of the autumn survey. Not corrected for catches between surveys.

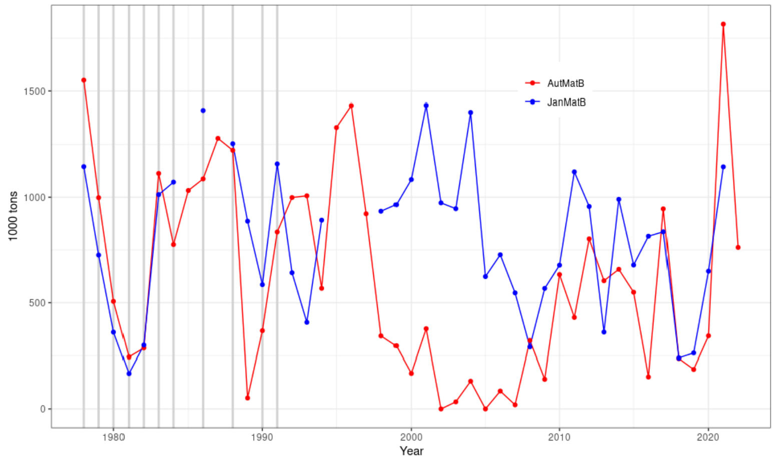


Figure 1.2: Biomass of mature capelin in autumn and winter. The year indicates year of the autumn survey. January survey corrected by adding catches between surveys. The grey vertical lines indicate the years listed in table 15.2 in the the book The Icelandic capelin stock.

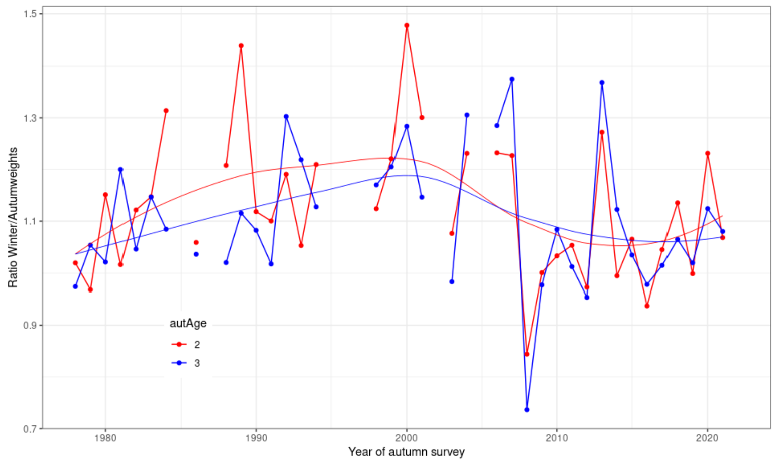


Figure 1.3: Ratio between mean weight at age in autumn and winter surveys. Age in the figure referes to age in the autumn survey.

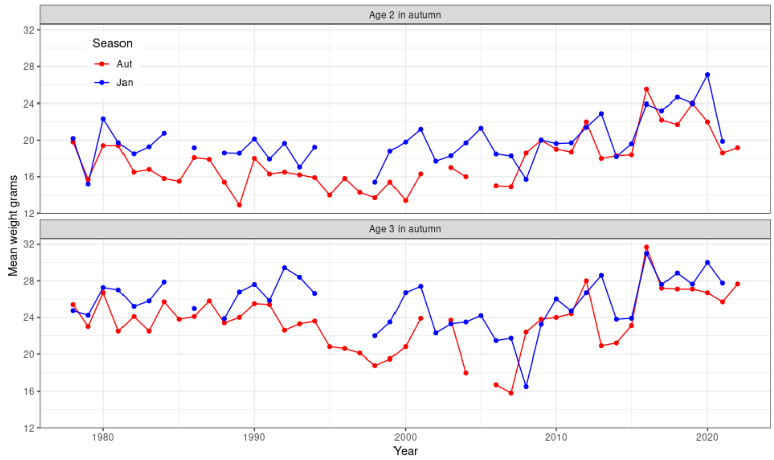


Figure 1.4: Development of mean weight at age in autumn and subsequent winter survey. Autumn survey extends one year longer as the 2022 autum survey is available.

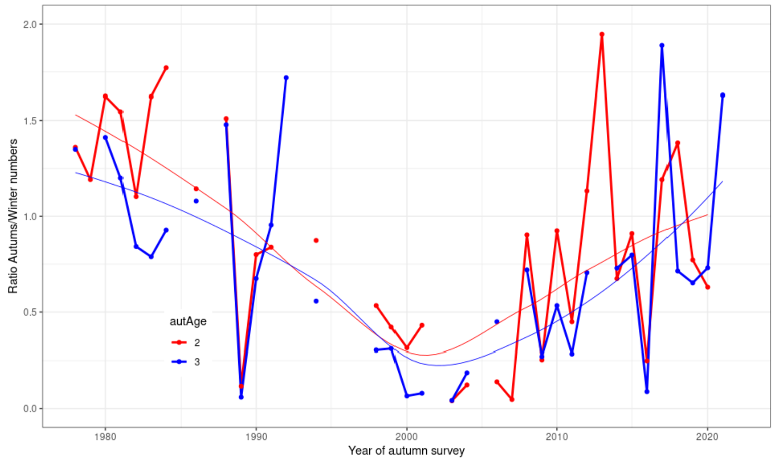


Figure 1.5: Development of ratio of numbers at age in autumn and subsequent winter survey. Autumn survey extends one year longer as the 2022 autum survey is available. Numbers not corrected for catches between surveys.

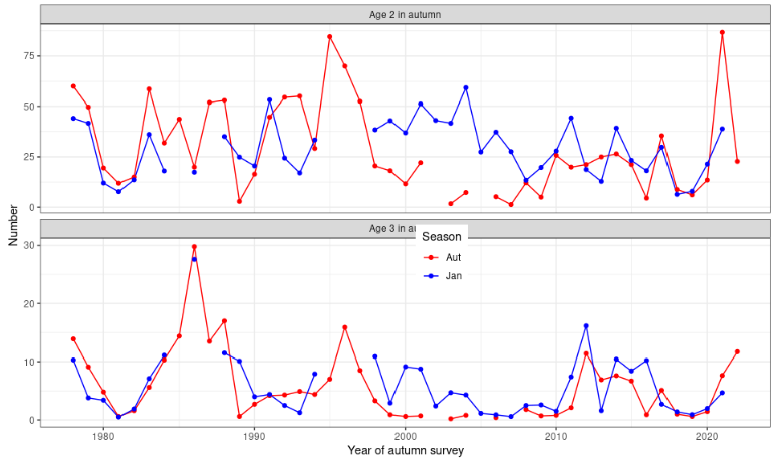


Figure 1.6: Development of numbers at age in autumn and subsequent winter survey. Autumn survey extends one year longer as the 2022 autum survey is available. Numbers not corrected for catches between surveys

The stock assessment model for IEGJ capelin is in principle very simple $q = 1$ in January surveys. The official assessment value is biomass of mature capelin January 15th, both average value and uncertainty.
The capelin will spawn and die 2 months later and the goal with the management is to ensure that enough capelin will spawn. Even though the prediction period is only 2 months, the predicted spawning stock is uncertain.

- The acoustic measurements have considerable uncertainty, the main sources are.
    1. Density of the survey transects and patchiness of capelin distribution.
    2. Capelin migration during survey.
    3. Breaks in survey coverage due to storms.
    4. Variability in the TS value.
- The capelin is subjected to high predation mortality during their spawning migration along the Icelandic continental shelf.
- Catches lead to increased relative uncertainty in the SSB.

In many seasons, multiple acoustic surveys are conducted, always one in the autumn and in most years one or more in the winter. In 4 cases, 1985/86, 1987/88, 1995/96 and 1996/97 the winter surveys were not conducted to save money as TAC obtained from the autumn measurements was already high (figures 1.1 and 1.2). For those that are interested in looking at the relationship between autumn and winter measurements this selective removal of years with high biomass in the autumn is not desirable. But the figures do clearly indicate worse relationship between autumn and winter surveys after 1991/92.

The acoustic surveys are very sensitive to timing, both autumn and winter surveys.

The winter surveys must be conducted after the mature stock enters the Icelandic continental shelf north of Iceland and before they migrate into the warm sea south east of Iceland when they take the usual eastern route. In many years, small part of the stock takes the western route and in 2001 most of the stock took that route. The timing of the migrations varies and in some years the first schools taking the normal eastern route have migrated into the warm sea (where acoustic measurements are unreliable) before the last one enter the continental shelf. In some cases different measurements or part of different measurements can be added, the main criterion to avoid double counting is that capelin found north-east and east of Iceland is going to migrate clockwise to the spawning grounds. Example for this kind of approach is from the 2021 assessment where capelin south of 65th degree was added to capelin north of 65th degree in a survey one week later.

When to take the average of surveys or let the highest value stand alone is always a matter of judgement. Estimated CV, age composition and spatial distribution compared to older measurements matter. Example is from 2017 when the 3rd measurement in beginning of February was 190% higher than the 2nd measurement in January. The age composition in the 3rd measurement was also quite different from the other two, with much higher proportion of the older yearclass. Depreciating the other two measurements was therefore justified. In 2017 the capelin arrived very late to the Icelandic continental shelf,most of the fisheries were conducted in March west of Iceland and there are indications that considerable part of the capelin took the western route to the spawning areas.

From what is described above winter surveys conducted in the warm sea should not be the basis of assessment nor winter surveys conducted late in the season in the north and north-west except large part of the stock arrives late.

Timing issues are also important in the autumn surveys. The capelin migrate north to 70 degree or further to feed and return in October-January, the tendency has been that they return later. After 2000 only part of the stock was covered in the autumn surveys (figure 1.1),the main reason was problems with drift ice in areas inhabited by capelin. Insufficient funding to cover the distributional area did also matter, limited funds were not spent on surveys with variable coverage. After 2009 the survey area was increased to the north but areas close to Greenland could not be covered due to ice. This problem has decreased after 2012 when the survey was moved to September when drift ice is at minimum. The price to be paid for earlier survey is larger survey area and more survey effort, increased difficulty in determining which capelin will spawn next year and longer period between autumn and winter measurements (potential for higher M). The possibility that small yearclasses are underestimated does also exist when the survey area is large.

The autumn surveys have some advantages compared to the winter surveys. The surveys are not conducted in a period of active migration so disruption due to weather is not as much of a problem. For the fishing industry information about TAC are obtained earlier so the companies have more time to prepare for the fishing season.

In 2015 (WD 13) a procedure to use autumn surveys to generate advice was described. This procedure used the observation from the period before 1993 that biomass of mature capelin in autumn and winter surveys was approximately the same when catches between the surveys had been accounted for (figure 1.2). This procedure is based on (Vilhjálmsson (1994)) that estimated M=0.035/month in October- January and ≈ 10% weight increase in the same period. After 1993 the relationship between autumn and winter surveys breaks down and for many years the biomass in autumn survey is much less than in the winter surveys. The exception is the autumn survey 2021 where the measured biomass is considerably higher than in January.

Looking at what is behind the assumption that biomass in autumn and winter surveys is the same, weights in winter surveys have in recent years been approximately 5% higher than in autumn surveys (figures 1.3, 1.4) but was close to 10% before 1994. Also M of 0.035 would be applied for 4 months instead of 3 as the acoustic measurement in autumn is conducted in September. This would lead to the difference between surveys of $e^{-0.035\times4} \times 1.05 = 0.91$ i.e the autumn survey biomass should be reduced by 9% + catches until January 15th. The data, (figure 1.2) do not suggest that the autumn biomass needs to be reduced, except in 2021 when the biomass is much higher than the biomass in winter 2022. What needs to be done here is to look specifically at 2021/2022.

Considerable changes in spatial distribution of capelin have been observed since the 90´s, earlier the mature capelin migrated north to feed but in October they were often found relatively close to the Icelandic continental shelf where the acoustic measurements were conducted. In recent years the capelin seem to return later (can be seen from cod stomach samples in demersal survey in October) and are in the September survey located at 69th - 71 degree north in east Greenland waters.

The main conclusion from these considerations is that care must be taken if winter measurements indicate a considerably smaller stock than 4 months old autumn measurements.

2 Agedistributions

In the assessment report for Icelandic capelin 1996 it is stated that “experience has shown that age distribution of catches in the winter fishery (January - March) reflects well the age distribution in the mature part of the stock.” Those age distributions are here compared to age distributions from the January surveys and autumn surveys in the same season (figure 2.1).

The results indicate that proportion of the older agegroup is usually lowest in the autumn survey but highest in catches. Historically the results are variable, sometimes the catches indicate considerably higher proportion of older agegroup than the survey.

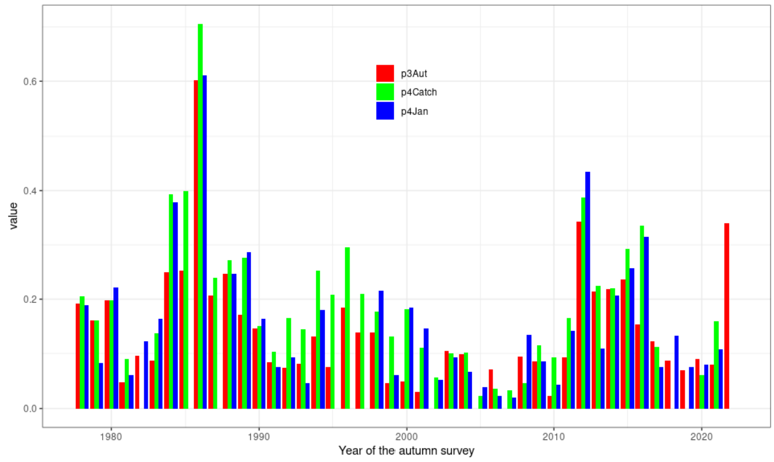


Figure 2.1: Proportion of age 3 and older in autumn measurements and stock. Stock is usually January survey back calculated by M=0.035/month and catch.

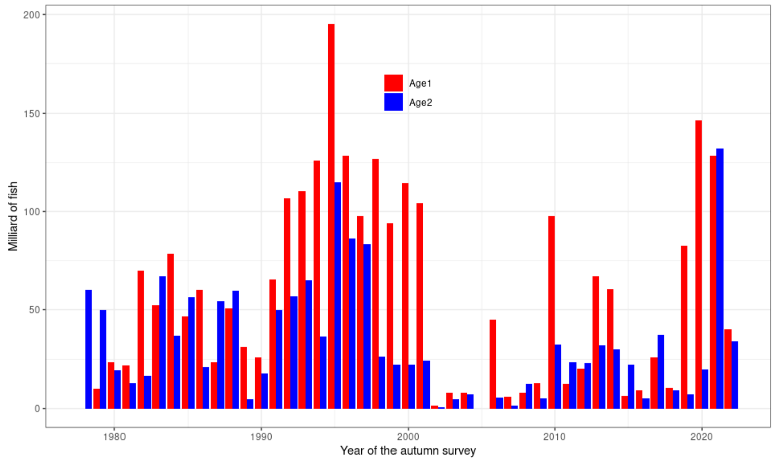


Figure 2.2: Index of age 1 (red line) and age 2 (blue line) in autumn surveys. Nearly all age 1 is immature and in most years mature capelin dominates in age 2

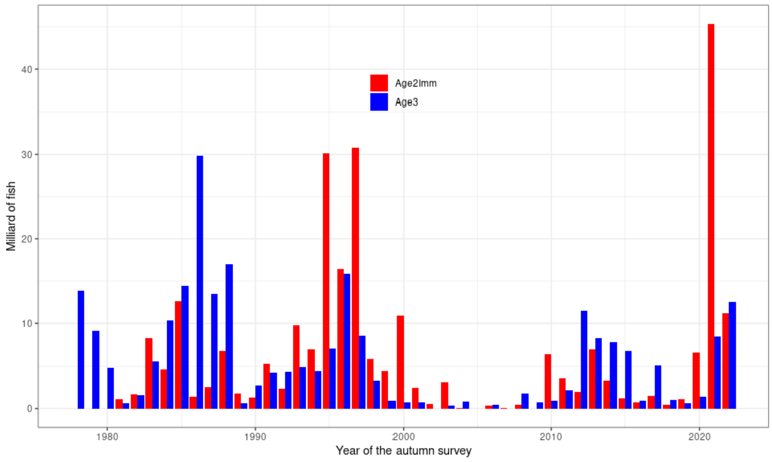


Figure 2.3: Index of immature age 2 and age 3 in autumn surveys

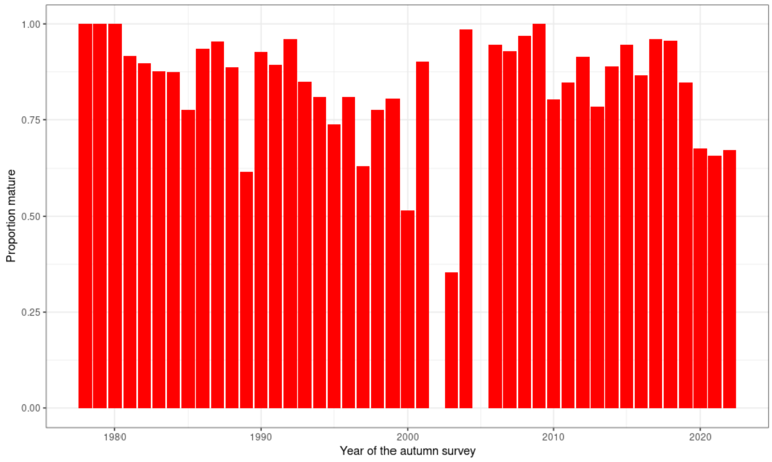


Figure 2.4: Proportion mature of age 2 in the autumn surveys. Some of the surveys have limited coverage, both in the beginning and the early 2000's.

3 Years 2020-2022

Biomass of mature capelin in the autumn survey 2021 was estimated 1833 thous. tonnes, age 3 was 10% of the total biomass and 8% of the total number. Age 1 was 1% of total number but age 2 was 91% of the total number of mature capelin. Looking at the number of age 1 and 2 in 2020 and 2021 (figure 2.2) the 2019 yearclass is the largest in the series. The number of age 2 immature is also the highest (figure 2.3). The number of age 3 in autumn 2022 is high but relatively much lower than older measurements of this yearclass (age 1 in 2020 and age 2 immature in 2021)

Looking at proportion mature in autumn 2021, for age 1 it was 1% , 65% for age 2 (the large yearclass) and 91% of age 3. 65% is relatively low proportion mature of age 2 (figure @(fig:propmaturecapelin2)), the lowest value observed is 40% for yearclass 1983 (the largest yearclass in the series) but proportion mature was very low for many of the yearclasses 1980-1985. 91% is also low proportion mature for age 3 in autumn, usually it is close to 100%.

In the latter January measurement 2022 the 2018 yearclass was 10.7% of the total number in the mature stock and 13 % of the biomass.

Comparison of autumn survey 2021 and the latter winter survey 2022 by yearclass, taking catches between surveys into account (SSN means numbers in mature part of the stock in the surveys.) is shown below (all numbers in milliards).

```
SSN September
yc2019  86.74 yc2018 7.63 milliards
SSN January
yc2019 38.91 yc2018  4.68  milliards
Catch between surveys.  285 kt. 12.37 milliards
yc2019 10.63  yc2018 1.73 milliards

M = 0.035*4

Predicted winter survey numbers from autumn survey and catches.

yc2018 $7.63 \times e^{-4x0.035}-1.73 = 4.90$
yc2019 $86.74 \times e^{-4x0.035}-10.63=64.77$

yc2018 is predicted $\frac{4.90}{4.68}$ higher or 4.7%.
yc2019 is predicted $\frac {64.77}{38.91}$ higher or 66.4%
```

Small complications in autumn survey 2021 is 0.75 billion of immature age 3 that should perhaps have been added to the mature part of stock as no age 4 fish were observed in autumn 2022 nor any other autumn survey.

The method described here is used in (Vilhjálmsson (1994)) to test quality of the detection of maturity in the autumn survey. There, the assumption is made that the maturity stage of all fishes in the older group are correctly identified (usually they are all mature).

The share of the older (2018) yearclass in catches was higher than in both the acoustic surveys, i.e the latter January measurement and the autumn survey. The discrepancy between the latter January survey and the autumn survey was more in the 2019 yearclass. In 2022 it was attempting to explain the observation by overestimation of proportion mature of the 2019 yearclass. It was certainly low but the yearclass was estimated very large and lower proportion mature had be seen in the 1983-yearclass for example. Identifying maturity stage in the autumn survey 2021 was claimed to be difficult by the research crew so this explanation was quite possible.

Results from the 2022 autumn survey indicate that this explanation might not work, the number of age 3 mature was only 25% of the number of age 2 immature the year before (M=0.115 per month). Comparing the surveys in 2020-2022 it looks really like there are yearfactors whatever causes that.

Final advice for 2021/2022 based on the average of the second January survey and Autumn survey would have been 853 thous. tonnes based on both surveys, 914 thous. tonnes based on the Autumn survey only and 639 thous. tonnes based on the second January survey only. If the advice of 853 tonnes had been caught and the second January survey was indicating the correct size of the stock the fifth percentile of SSB would have been close to 0 and average SSB 180 thous. tonnes according to the prediction model.

Catch after January 15th is now estimated 511 thous tonnes and 185 thous tonnes before January 15th. Prediction from the January survey only, based on this catch leads to 5th percentile of SSB = 102 thous tonnes and average SSB of 330 thous. tons. Based on Autumn 2021 only and the same catches 5th percentile of SSB would have been 358 thous. tonnes and average SSB 900 thous. tonnes.

There are indications that the biomass of capelin in Icelandic waters in winter 2022 was overestimated by using results from the autumn survey 2021, the advice last season was too high, the allocated quota was not caught and CPUE in the pelagic trawl fisheries was relatively low (WD ?) . Part of the explanation could be that the weather last winter was very unsettled, especially in the south and west and might have disturbed the fisheries in February and March.

Everything points to the conclusion that the wintersurvey 2022 gives more credible account of the fishable stock in winter 2022 than the autumn survey 2021.

There are few ways to proceed here.

1. Correct the autumn survey for age ratio in winter survey. The proportion of the older agegroup in the autumn survey is 8% but 10.7% in the January survey. To get this proportion the number of the younger agegroup in the autumn survey must be multiplied by $\frac{(1-0.107)\times 0.08}{(1-0.08)\times 0.107} = 0.725$. This will scale the survey biomass down from 1833 to 1378 thous. tonnes, closer to the winter survey taking into account catch of 285 thous. tonnes between the surveys. 13.9% of those catches (in numbers) were from the older agegroup that might be used in similar way to reduce the autumn biomass even further. The approach described here does not account for account

catches between the surveys that take uneven proportion of the yearclasses. Also the existence of age 3 immature in the autumn might be questioned.

2. The method above is not strictly correct if relatively high proportion of the older age groups is caught between surveys.

```
yc2018 $7.63 \times e^{-4x0.035}-1.73 = 4.90$
yc2019 $86.74 \times e^{-4x0.035}-10.63=64.77$
```

To get 10.7% proportion of the older age groups in the January survey the mature part of the younger age group need to be reduced from 86.74 to 57 milliard or by 35%. Including the immature part of age 3 the starting numbers would be $7.63 + 0.75 = 8.38$.

```
yc2018 $8.33 \times e^{-4x0.035}-1.73 = 5.55$
yc2019 $86.74 \times e^{-4x0.035}-10.63=64.77$
```

Here yearclass 2019 in the autumn survey would have to be reduced by 25%.

3. Correct the autumn survey for age ratio in catches. The proportion of the older agegroup in the catches is variable, 17.3% in December, 12.9% in January, 19% in February and 18.6% in March. The number of samples are 16 in December, 48 in January, 32 in February and 17 in March. For the whole season the proportion is 16% which will reduce the number of age 2 in the autumn survey to $\frac{(1-0.16)\times 0.08}{(1-0.08)\times 0.16} = 0.46$. One problem with this approach is that information of agedistribution in catches might not be available until too late.

4. Just base the advice on the winter survey or give the winter survey more weight in the average as it represents more recent measurements.

5. Compile the advice based on the average of plausible surveys but limit the advice to $B_{low} \times HR_{cap}$ where B_{low} is the biomass from that of plausible surveys that indicates the lowest biomass. HR_{cap} needs to be defined.

All those methods would probably work. Correcting the age distributions seem like a reasonable way to proceed, especially as it might not be clear in September which capelin are going to spawn next winter. This approach is also related to the length based approach described for the Barents Sea at the meeting. The difference compared to the Barents sea is that for the IEGJ capelin stock, not including the autumn survey in the final assessment is a possibility. Looking at the age distributions would then be more to understand what is going on.

Yearclasses 2019 and 2020 will account for the fishable stock in next winter fishery and more information on the size of those yearclasses will be available in late March 2023.

4 Consistency in autumn measurements.

Relationship between measurements of immature age 2 and mature age 3 capelin shows interesting trends. For yearclasses until yearclass 1990, more was usually measured of mature age 3 than immature age 2 of the same yearclass the year before while the opposite is true for yearclasses 1991-2001. One of the differences between the eighties and nineties is autumn fishery vs summer fishery i.e. in the former period most of the catches in the summer-autumn period are taken during or after the survey but before the survey in the latter period. The number of age 3 mature in autumn 2022 is only 25% of the number of age 2 immature in autumn 2021, the largest drop for many years.

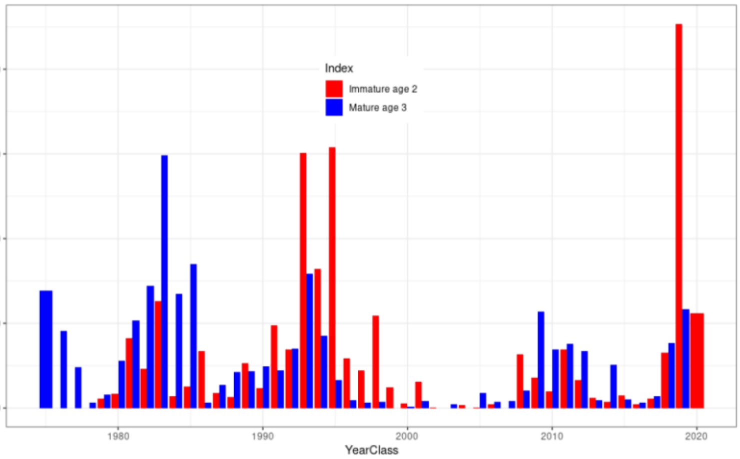
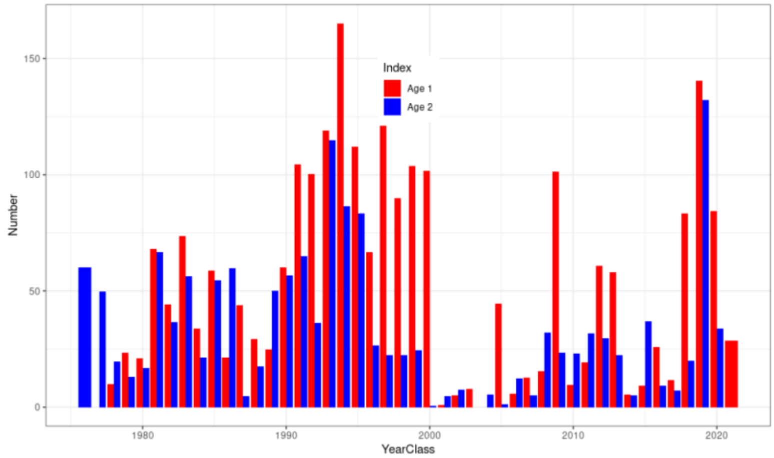
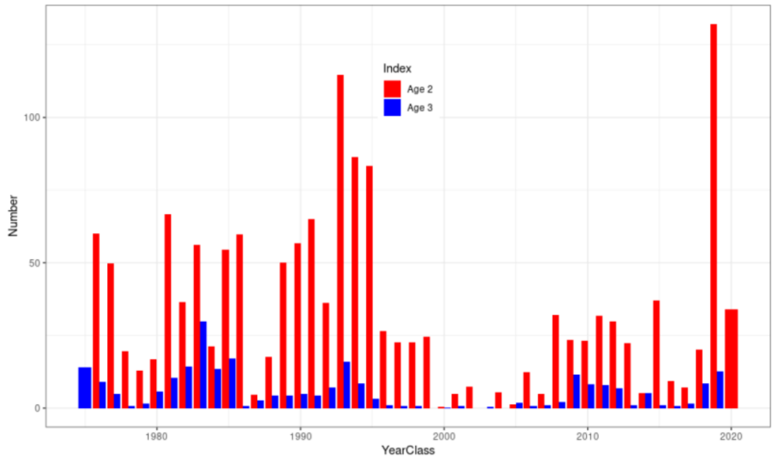


Figure 4.1: Indices of age 2 immature and age 3 mature in the following year in the autumn survey





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Working document I02. Coefficient of Variation of Surveys

Warsha Singh

During the benchmark meeting a request was made to compile the coefficient of variation (CV) of all autumn and winter surveys as far back in time as possible. The objective was to visualize the fluctuations in CV of the autumn and winter surveys over time, and between the autumn survey, individual winter surveys, and the CV of the combined final advice. There are also instances where more than one advice is issued per fishing season, and it was of interest to examine how the CV differs among these. There are also instances when autumn and winter surveys are combined to generate the advice and the implication on the estimated final CV needs to be assessed.

The overarching goal of this exercise was to determine whether an average CV could be used over the years instead of estimating CV every year given the high variability in estimated CVs.

The CVs were compiled from 2013 to 2022. There are considerable fluctuations over time as can be seen in Figure 1 below. The autumn CV fluctuates between 0.2 – 0.3. The surveys that were combined to generate the final advice are delineated in Table 1. The reasoning for the huge differences between the individual winter surveys sometimes is because some of the surveys are partial coverages conducted in appropriate weather windows. These could also differ in the spatial area covered. The CV plotted here for the final advice were regenerated and may slightly differ from the published values in assessment reports.

During this time period, there were two instances when the autumn survey was combined with the winter survey to generate the final advice. The justification for following this approach in 2018 was to lower the CV of the final advice. The autumn and winter surveys gave similar biomass estimates during this fishing season therefore this was considered warranted. In 2022, the combination of the two surveys is more questionable.

These acoustic surveys in general have a high CV because of the patchy distribution of the stock. For instance, along the East Coast of Greenland high acoustic registrations can be seen close to the coast during the survey. Similarily, during the winter survey, the tight schools of high concentrations can be seen unevenly distributed in the survey area. By doing a finer-scale survey in areas of high concentrations one can introduce the problem of underestimating the total biomass in the survey region. Therefore, identifying a bound on the CV or taking an average may be a better approach to control the uncertainty in the survey estimate instead of estimating by survey which could be tracking the noise in the data.

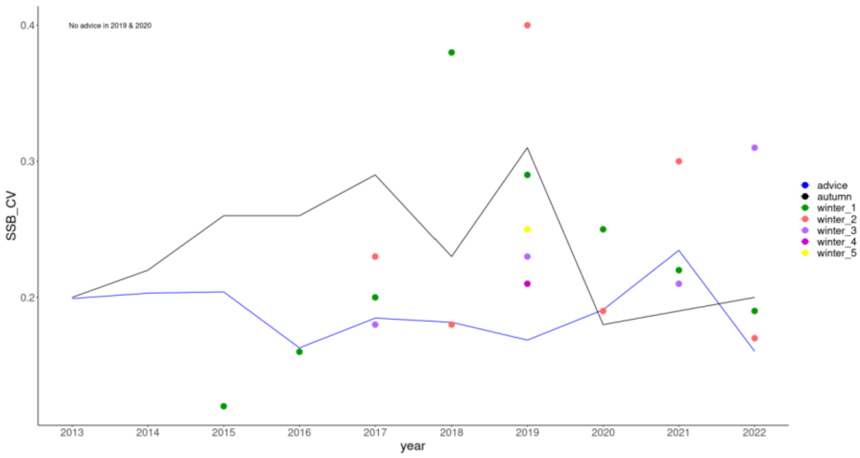

Figure 1: Coefficient of variation (CV) of surveys by autumn (black line), individual winter surveys (colored dots), and final advice (blue line) for years 2013-2022. No advice was issued in 2019 and 2020 winter season.

Table 1: Winter and autumn surveys conducted with the combination of surveys used for advice for 2013-2022.

Fishing Year	Year	Number of winter surveys	Number of surveys used for advice	Survey used for final advice	Final TAC
2015/2016	2016	1	1	Winter 3-21 Jan	173
2016/2017	2017	3	1	Winter 3-11 Feb	299
2017/2018	2018	2	3	**Autumn**, Winter 17-22 Jan, 25-31 Jan	285
2018/2019	2019	5			0
2019/2020	2020	3			0
2020/2021	2021	3	1	Dec	21.8
2020/2021	2021	3	1	4-9 Jan	61
2020/2021	2021	3	2	17-20 Jan south of 65N 26-30 Jan north of 65N	127.3
2021/2022	2022	2	2	**Autumn**, 25 Jan - 2 Feb	869.6

Working document I03. Predation model for IEGJM capelin.

The predation model was discussed in some detail at WKCAPELIN 2022. The model was described in WD11 at the WKICE2015. The model is designed to cover predation on the main spawning migration of capelin. A schematic description of the model is in Figure 1.

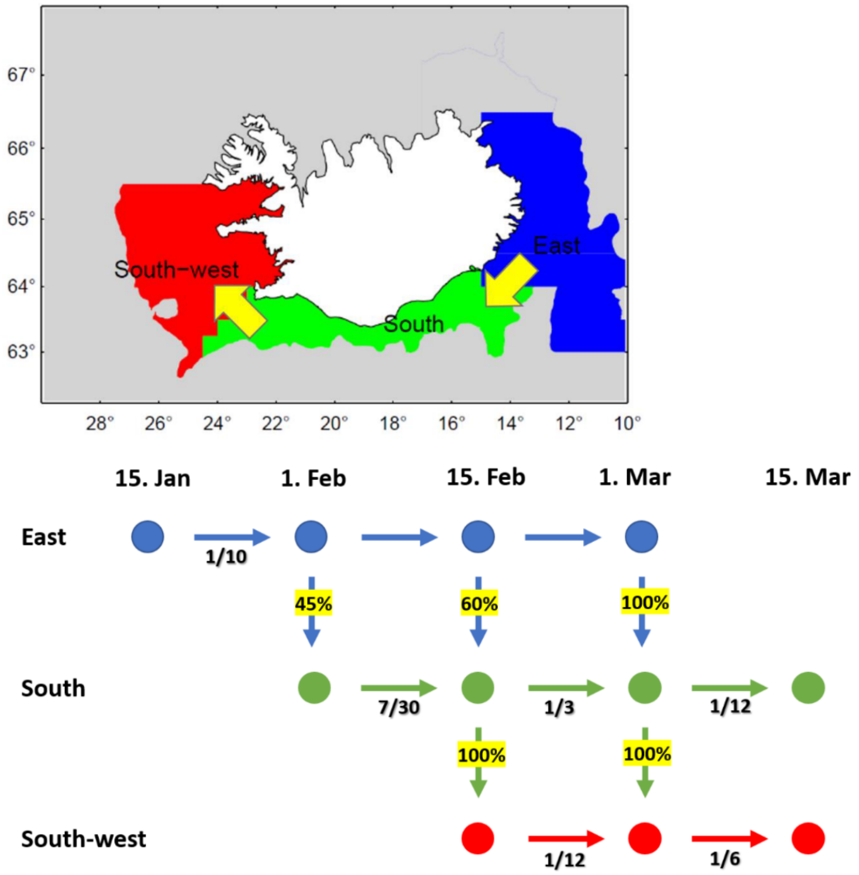

Figure 1. Top: The 3 regions used in the simulations of predation on the eastern capelin migration with yellow arrows showing migration route. Bottom: Schematic showing proportional distribution of migrations and catches in the predation model as discretized over 2 week intervals. Catches are shown as fractions below horizontal arrows and clockwise migrations are given as percentages over vertical arrows.

The predation model only applies to the stock component that migrates the clockwise route around Iceland. In most years, majority of the stock has migrated that route and nearly all the catches have been taken from that component.

All the capelin stock is assumed to be in the east on 15th of January, and on 15th of March, it is assumed that all the capelin stock spawns in the south and southwest, a higher proportion in the southwest.

The predators (cod, haddock and saithe) are assumed to be stationary during the period of capelin migration and their spatial distribution is obtained from the demersal survey in March from 1985 to previous year. The total abundance of each predator is predictions for the current year based on assessment in previous year. The proportion of predators in each area for each replica is randomly selected from the proportions in the March survey since 1985.

Most capelin catches are taken in the southern area in February while large part of the predation occurs in the eastern area from January 15th to February 15th. During most of the historical period (from 1985 to 2015), the goal was to leave 400 thousand tons of capelin for spawning so according to the bookkeeping, the amount left in the south and southwest in March is similar from year to year.

The predators in each area are assumed to only prey on the capelin spawning migration for 4-6 weeks, the time that it takes for the main spawning migration to migrate through each area. The most important series of predators' stomach data is from the demersal survey, usually collected from 1st to 20th of March, near and in the capelin spawning period. Those stomach samples show in many years, consumption of capelin in the north, north-west and northeast, as well as on the main spawning grounds of capelin south of Iceland (figure 4). This capelin found in the stomachs in the north is a mixture of immature capelin and later arriving schools that could either take the western route to the usual spawning areas or spawn in the north. In most years, there are later arriving capelin schools and in 2 cases (1979 and 2001) most of the spawning migration took this western route. Those late-arriving capelin schools are a reserve buffer for the spawning stock. However, they should not be included in the advice to increase fisheries on the central capelin migration.

The predation model is based on a type II feeding function with two parameters: maximum consumption and half feeding value. There is limited knowledge of both those parameters, so a relatively wide uniform distribution was put on both of these parameters (figure 2), and these parameters were not correlated. Tests on the sensitivity of the main results to the normal distribution of the parameters were conducted (figures 2 and 3), indicating that the variability in the predation parameters has little effect. The largest variability in the model comes from the bootstrap of the spatial distribution of the predators in the survey.

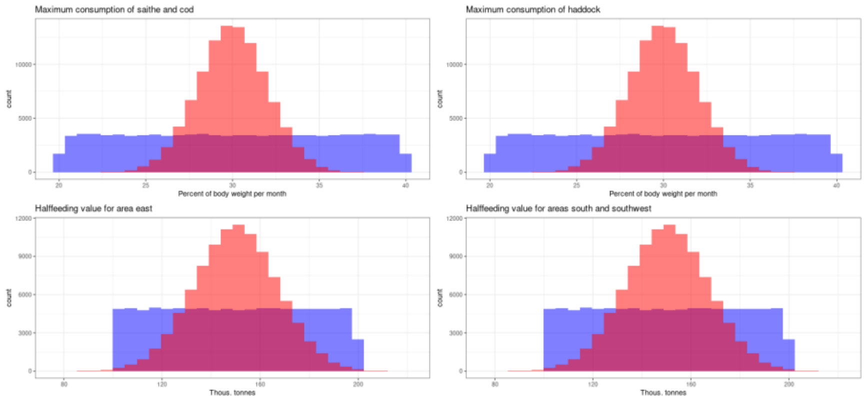

Figure 2. Original distribution of predation parameters (blue) and the modified one (red). The average is the same used in all panels. The upper panels indicate maximum predation by top predators. The lower panels show half feeding value in each area.

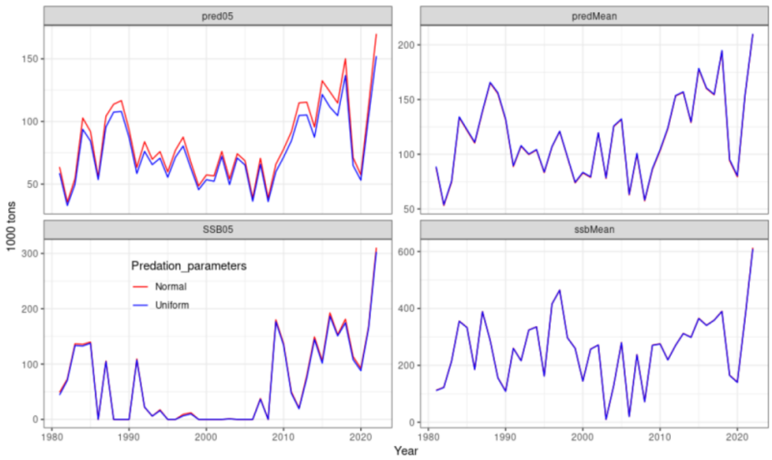

Figure 3. Average and fifth percentile of SSB and predation for the different sets of parameters tested in figure 2. Pred05 and SSB05 are fifth percentile of predation and SSB.

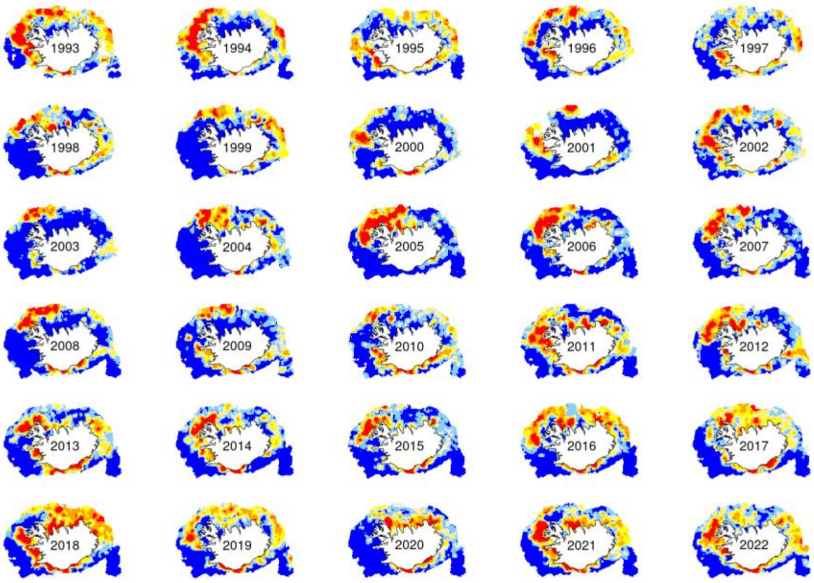

Figure 4. Capelin in cod stomachs in March 1993-2022 shown as stomach fullness.

Working document I04. Calculations of the spawning stock biomass from 1981-2022, estimation of B_{lim} and advice given by the HCR from 2015.

This working document describes compilation of the spawning stock biomass historically, estimation of B_{lim} and comparison of advice according to the HCR adopted in 2015 and the old method. It is based on most other chapters where things like description of the surveys, history of advice, TS value, evaluation of uncertainty and predation are discussed in more detail towards the end of this working document.

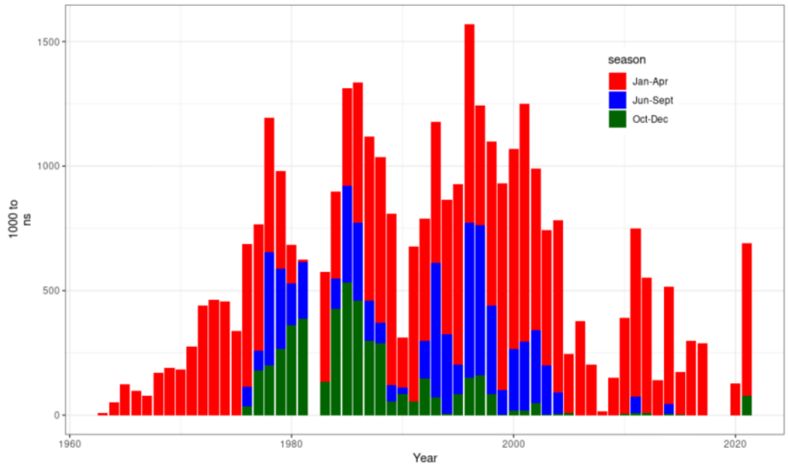

Figure 1: Catch by season, 1981 means 1981/1982 season, i.e from June 1981 - April 1982

The goal with management of Icelandic capelin has always been to leave a large enough spawning stock biomass to ensure stock productivity and, since 2020, to also leave capelin for the ecosystem, which has been done by starting the capelin fisheries relatively late (October 15th vs July 1st). From 1980 - 2015 the goal was to leave 400 thous. tonnes of capelin spawning but since 2016 the goal has been $P(SSB < Blim) < 0.05$. In addition, more predation has been included since 2016 and predation is linked with estimated stock size of cod, haddock and saithe.

The change in methodology in management of the Icelandic capelin fisheries originated at an ICES benchmark meeting in 2009 (ICES 2009) where the methodology used at that time was not approved, as consumption estimates were considered too small and the uncertainty in acoustic measurements was not modelled even though some of the acoustic measurements from 2002-2009 were very uncertain. The methodology introduced in 2015 was in response to the comments from WKSHORT. It can be looked at as an adaptation of the method used in the Barents Sea to the situation in Iceland.

The new HCR was evaluated by ICES in 2015 (ICES 2015) and found to be precautionary. The value of B_{lim} was "estimated" to be 150 kt, based on the average of estimated SSB in 1981, 1982 and 1990. Those were the 3 lowest values of SSB, compiled in the old way, which produced average year classes. They were though based on SSB not compiled in the same way as done now and needed to be checked.

The SSB has now been recompiled for the years 1981-2022, using the model adopted in 2015, i.e. taking into account uncertainty in the acoustic measurements and using the predation model adopted in 2015. Uncertainty in acoustic measurements was recompiled for the years 2002-2006 and 2012-2014 by recalculating the acoustic indices and bootstrapping the results. Additionally, uncertainty was available for the years since 2015 when the advice has been given based on the new HCR. For earlier years the CV in the acoustic measurements was estimated by looking at survey reports as well as text from (Vilhjálmsson 1994). The CV was estimated to be in the range of 0.15-0.25 and included as a lognormal multiplier on the average value that was available in tables from the same sources.

The average value of the spawning stock (figures 3 and 5) is, in nearly all years, considerably lower than the 400 thous tonnes that was the official spawning stock according to the escapement rule.. Looking at the whole time period, the average SSB is 245 thous. tonnes, average catch 400 thous. tonnes and average predation 114 thous. tonnes. Catch refers to catch taken after the "final" survey, usually the majority of the winter catch. Estimating which catches were after the survey was often difficult as heavy fisheries were taking place when the survey was conducted. Excluding predation, the average SSB would be 365 thous tonnes. Only 6 times in the time series is the fifth percentile of SSB (including predation) larger than 150 thous. tonnes (2009 and 2016-2020).

Excluding predation, the fifth percentile of the spawning stock is in 18 cases of 39 cases above 150 kt and 6 cases less than 0, in the years 2000 and 2002-2006. In all those years where the fifth percentile is less than 0 the harvest rate was quite high, averaging around 76% and the average catch was 582 thous. tonnes. The years 2003 and 2005 deserve special attention. Re-analysing of the indices in 2003 led to a substantial reduction in the average biomass (harvest rate exceeds 100%) but the CV is reasonable (0.2). The 2005 acoustic measurement has always been known to be very uncertain (CV=0.45, figure 2).

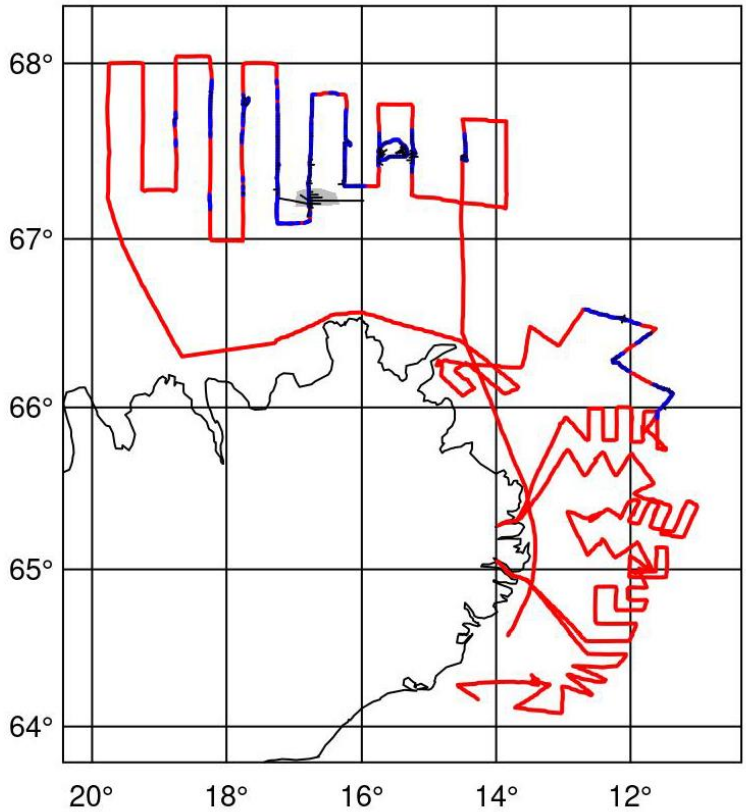

Figure 2. Acoustic survey in January 2005. The red lines indicate no capelin, and the blue lines capelin. Size of black bars is proportional to amount of capelin. 40% of the capelin biomass is in the small grey area.

In one case (2003) the average SSB is < 0, in that year the average of recompiled indices is lower than the original value and the catch after the survey exceeds survey biomass. In that specific year, later migration was suspected. An additional factor might be that catches in January 2003 were the highest in the time series and mostly taken by pelagic trawl. Do fisheries by pelagic trawl affect the TS value??

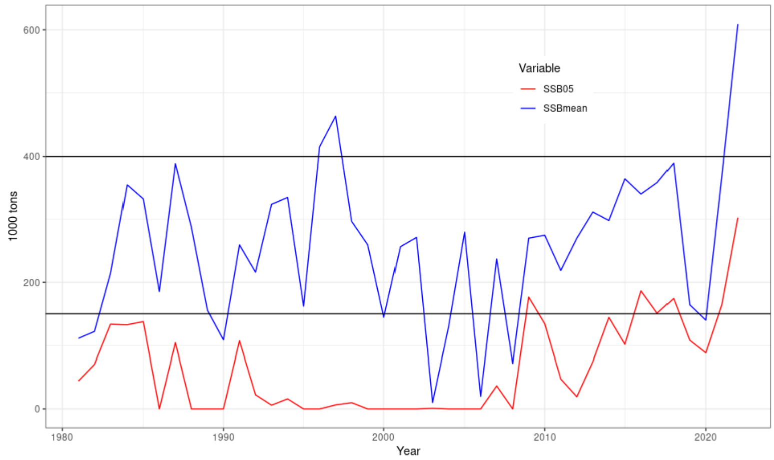

Figure 3: Average SSB and 5th percentile of SSB. The horizontal line show Blim=150kt and the old escapement biomass of 400 kt. To allow the figure to look reasonable values less than 0 are changed to 0 but as described in the text values less than zero appear.

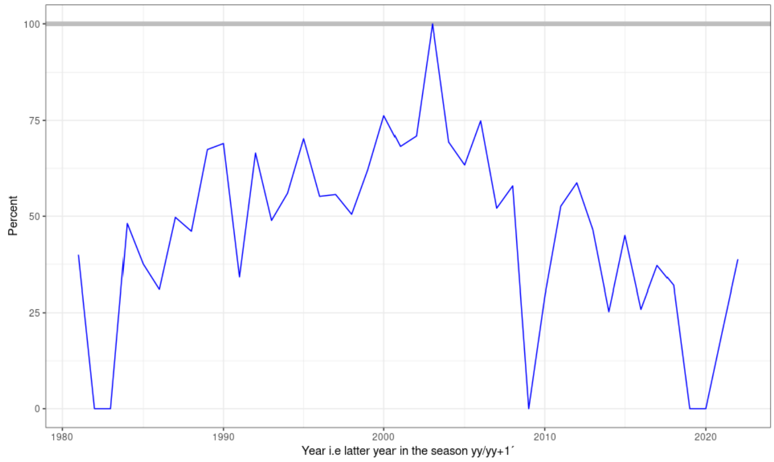

Figure 4: Harvest rate (%) defined as the catch after the last survey divided by average biomass from that survey. The horizontal line shows 100%

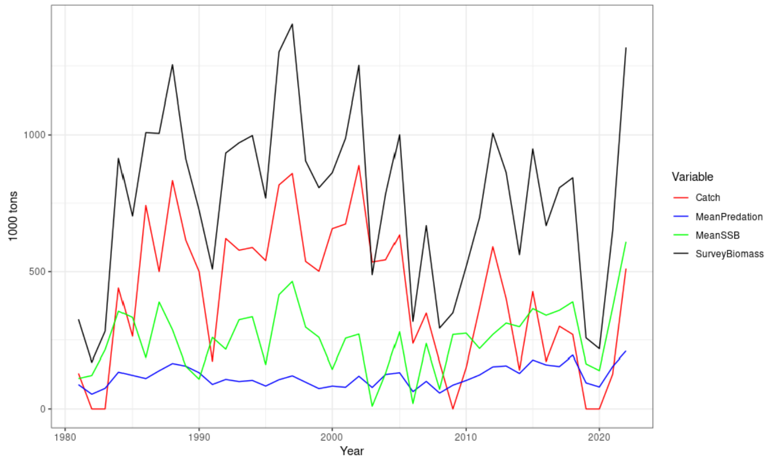

Figure 5: Survey biomass, catch after survey, predation and mean SSB.

The CV of SSB is in many years quite high (figure 6). This problem is made worse when a large part of the measured biomass is removed and, ignoring predation, we end up with the same standard deviation in the spawning stock as in the survey biomass but with much lower biomass in the spawning stock. . Predation increases the uncertainty further.

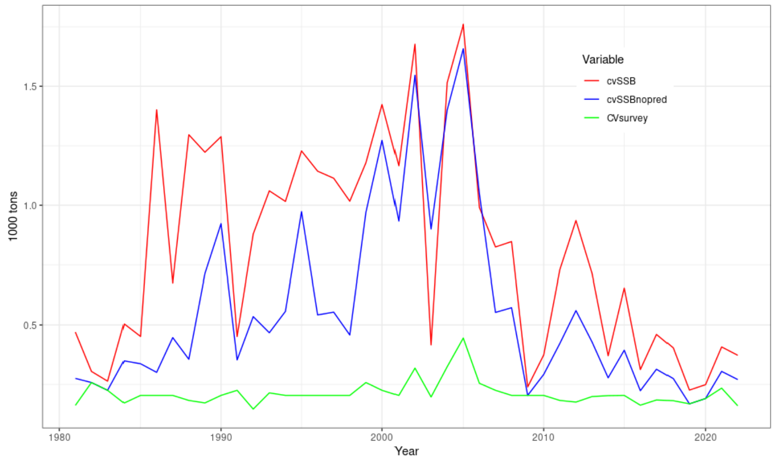

Figure 6: CV of survey, SSB and SSB excluding predation

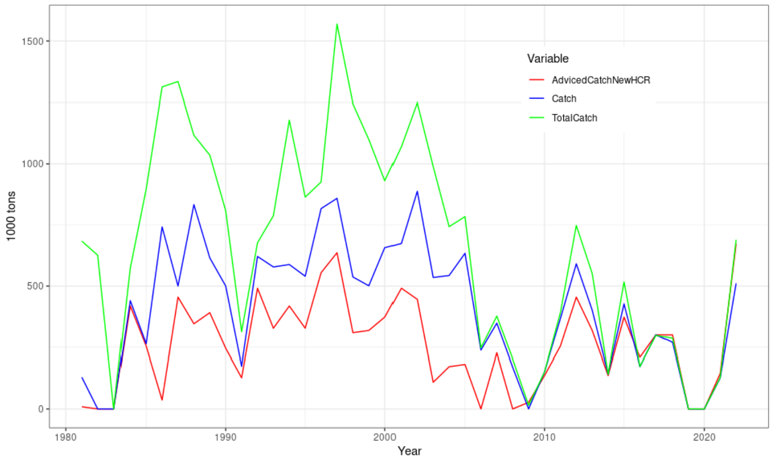

Figure 7: Catch after survey (red) and catch advice (blue) according to the new management plan. The green line shows the total catch of the season, between the green and red line are the fisheries before final survey. (summer and part of autumn fisheries).

Historical catch advice according to the new HCR is nearly always lower than the catch taken (figure 7), the exception is in the years 2016-2022 where the advice is given according to the new HCR. The average difference for the years 1981-2015 is 190 thous. tonnes but in some of those years the catches might have exceeded what it should have been according to the old management plan (problems with initial quota). In the years 2016-2018 the catch is slightly lower than would be calculated now, the reason is the overestimation of the biomass of cod and saithe in those years. In 2022 the catches were less than the TAC. In most years before 2003 a considerable part of the total catch in the season is taken before the "final survey" (figure 1), leading to the difference in total catch and total catch advice being relatively less than the difference in "catch after final survey."

The main purpose of protecting the spawning stock of capelin is to increase the probability of good recruitment or perhaps more precisely to reduce the probability of recruitment failure. This is not the only gain, as a large biomass of spawning capelin must be beneficial for the ecosystem and 1-2 million tonnes of capelin have often spawned before the capelin fisheries started.

There are a few different measures of recruitment and or SSB.

1. 0 group survey conducted in August 1970-2003
2. Amount of capelin in cod stomachs in the demersal survey in March (spawning time of capelin)
3. Indices of acoustic measurements of age 1 capelin.

4. Indices of the year class at age 3 and 4 scaled to age 2 by adding catches taken from the yearclass before the acoustic measurements and using M=0.035 per month. (Back calculated number of age 2 at January 1st).

Of those measures the last one would be expected to give the best indication about the productivity of the year class, at least in terms of catches. On the other hand, the 0-group survey and the stomach data are more of an indicator of the size of the spawning stock that produced the 0 group than the amount of age 2 recruits from the year class. If the 0 group survey was a good indicator of SSB, then discontinuing it was a mistake. The goal of management of the capelin stock is in terms of the spawning stock so having a measure of the spawning stock is important.

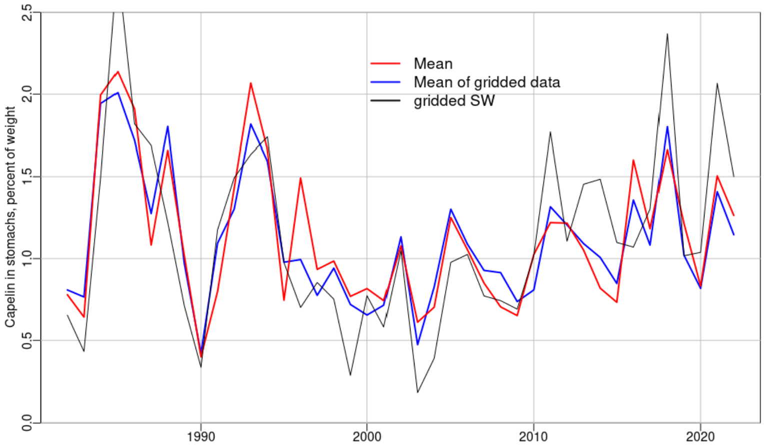

Figure 8: Indices of spawning capelin 1982:2022 based on stomach data from the demersal survey in March (SMB). The sampling has been comparable since 1996, but different before 1992. SW refers to the most important spawning area of capelin in the south-west.

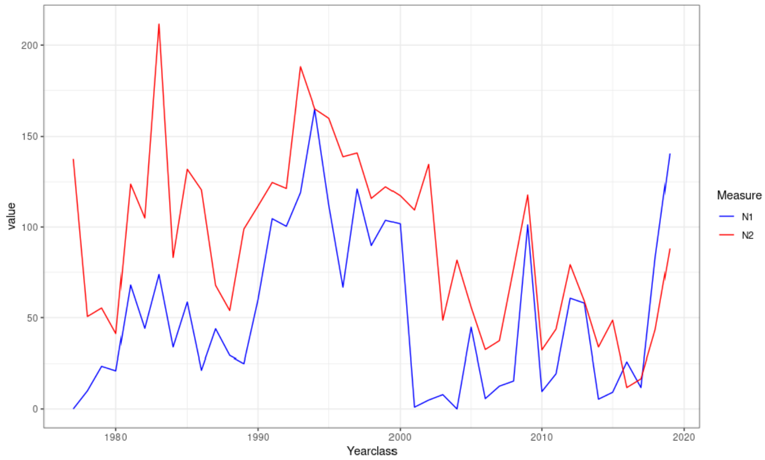

Figure 9: Back calculated number of age 2 at January 1st and acoustic measurement of the same year class at age 1. Units are milliard of fish.

The recruitment index (N1) gives a different picture compared to the back calculated catches and acoustic measurements at age 3 and 4 (figures 9 and 10). The indices at age 1 are relatively high in the nineties but very low from 2000 to 2008 and in the eighties. There have been a number of problems with the age 1 index. The spatial distribution of the recruits relative to ice cover is one of the problems, and the other is the amount of time allocated for the survey. The timing of the acoustic measurements in the autumn has changed and in the last 10 years they have been conducted in September to minimize problems with ice. Earlier they were conducted in October or November, and in those years the capelin were closer to Iceland but still ice was often a problem.

In the 1980's more effort was put into getting a good estimate of the mature part of the stock in autumn but later more emphasis was put on the immature part of the stock to get "initial quota."

The most recent year classes in figure 10 are outliers. The measurement of the 2018 year class at age 1 was always flagged as suspicious by MRI as the CV in the acoustic measurements was very high (~0.5). The same cannot be said about the 2019 yearlass, CV of the index at age 1 was not high and it was also very large at age 2 in the autumn survey 2021 but has been estimated smaller in later measurements (winter 2022 and autumn 2022). The number for the 2019 year class is not final as it will contribute to the mature part of the stock in winter 2023.

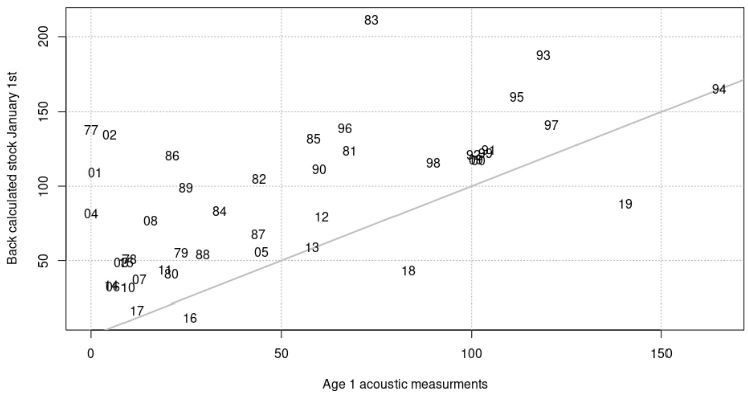

Figure 10: Back calculated number of age 2 at January 1st vs acoustic measurement of the same year class at age 1. Units are milliard of fish. The grey line shows 1:1 relationship.

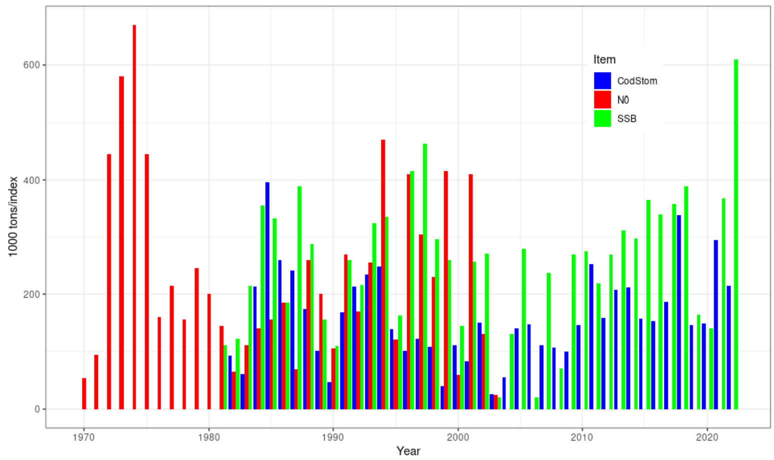

Figure 11: Development of the spawning stock of capelin , 0 group index and index from cod stomachs in March. The index from cod stomachs is based on stomachs in the main spawning area of capelin.

The results from the 0 group survey (figure 11) show the highest values before the capelin fisheries started, which is not unexpected for an 0 group survey that can be an indicator of the spawning stock. The last value in 2003 is the lowest but that is also a year with very low spawning stock as well as increased temperature. The low values in the beginning of the series (1970-1971) are interesting, well before any real capelin fisheries.

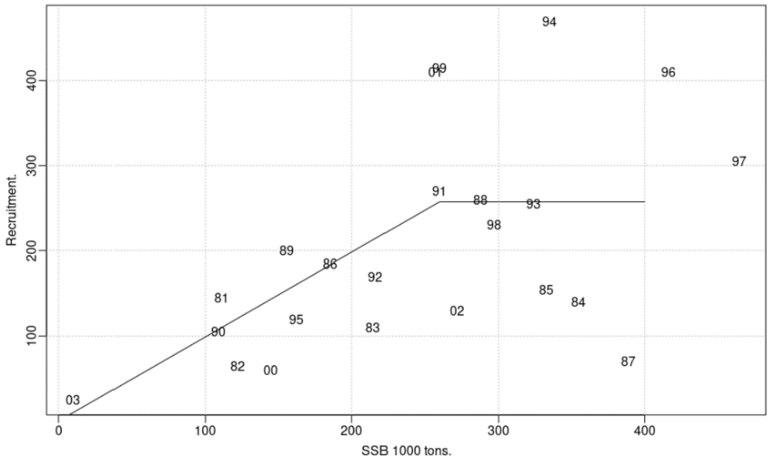

Figure 12: 0 group index vs spawning stock of capelin.

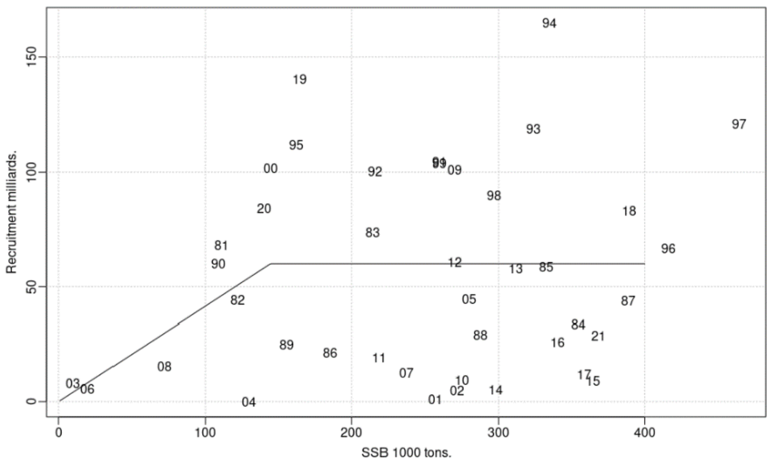

Figure 13: Index of age 1 from acoustic measurements vs estimated spawning stock

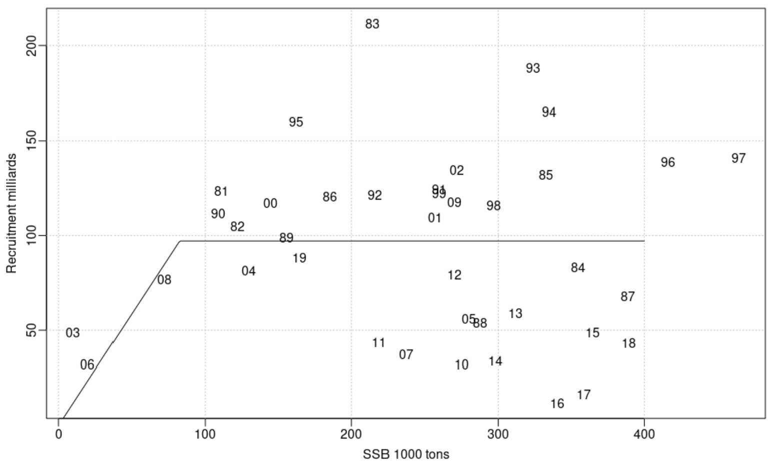

Figure 14: Back calculated N2 January 1st vs estimated spawning stock

Fitting hockey stick stock - recruitment functions, leads to $SSB_{break} = 257kt$ if based on the 0 group survey , $SSB_{break} = 144kt$ if based on N_1 and $82kt$ if based on N2. (figures 12, 13 and 14). A high value based on the 0 group survey is expected as it might be a candidate for a linear relationship with the SSB that produced it. The time series of the 0 group survey is of course shorter than for the other data series.

The results of WKCAPELIN-2022 was to base B_{lim} on the same years as in WKICE-2015 i.e 1981,1982 and 1990 (see figure 14). The result is $B_{lim} = 114$ thous. tons, compared to 150 thous. in 2015, based on spawning stock compiled the old way.

Recalculations of the spawning stock using the methodology proposed in 2015 show that the estimated spawning stock of capelin is very low in many years and the 5th percentile is negative. In many of those years a large part of the acoustic biomass is removed and relative uncertainty in the spawning stock is in those cases many times higher than the survey uncertainty.

There are number of possible explanations for this result.

1. The old management plan of leaving 400 thous tonnes for spawning leads to high harvest rate when the stock is large. This is a built in feature of escapement strategies, reduced when uncertainty in the spawning stock is taken into account.
2. Not all the stock was measured. In many years there are indications of later migrations, and some of them might be unnoticed. The winter surveys are sensitive to timing, the capelin can only be measured from the time when they enter the Icelandic continental shelf north of Iceland until they migrate into the warm sea SE of Iceland. Too long time between first and last schools causes problems.

3. TS value used is too high. The value used in Iceland is though 0.5 dB lower than that used in the Barents Sea. In most years the advice in Iceland has been based on winter surveys where TS values used should perhaps be different than the TS values used in the autumn surveys.

4. The variability of the TS value is a problem that needs to be investigated. The MFRI owns equipment for in situ measurements of the TS value but to do that requires time. What has happened in the surveys in 2020-2022 is difficult to explain by other factors.

5. Overestimation of the CV in the survey.

6. Overestimation of the predation.
7. Many of the older surveys were conducted from SE - NW against the migration to avoid losing the first schools into the warm sea before measuring them. Running a survey against migration leads to underestimate.

8. Estimation of the maturity stage in autumn survey can be a problem, especially after they were moved forward to September.

All those explanations are plausible, and the same explanation does not need to apply to each year.

Comment to be discussed **Looking at the winter surveys, a survey conducted in a relatively short time without a break should not be an overestimate of the abundance in the survey area if the CV is low. If the estimated CV is high the mean might be an overestimate but the advice is based on the 5th percentile. The TS value is probably variable, but the low measurements could be associated with fish that has released air from the swimming bladder (point 3 above). Different measurements can be combined either by summing or averaging. Summing measurements taken at different times requires thorough consideration that nothing is double counted. Averaging measurements that are more different than the estimated CV would indicate requires thorough considerations.**

Looking at the catches the average catch for fishing seasons 1995/96 to 2002/2003 is 1134 thous tonnes and the minimum catch 930 thous tonnes. In the seasons 2005/2006 to 2011/2012 the average catch is on the other hand 230 thous tonnes. Year classes 2003-2007 are all very small and looking at the data now, fisheries induced depletion of the spawning stock in those years cannot be excluded. The environment became less favourable for the capelin (increasing temperature) and the fisheries did not reduce in line with that. In some of those years, fisheries succeeded surprisingly well landing considerable amount of capelin in short time. Are CPUE of capelin indicator of stocksize?

Fisheries by season (figure 1) show that before 2003 substantial proportion of the fisheries were summer and autumn fisheries, but since then only winter fisheries. The main reason for the change around 2003 was that acoustic measurements of immature capelin “did not succeed" so the initial quota could not be allocated. The change in timing of the fisheries around 1990 from mostly autumn fisheries to mostly summer fisheries is interesting because in the nineties acoustic measurements of the mature stock in autumn often indicated a large stock, still the fisheries did not succeed.

Ongoing research on TS value of capelin seems to indicate that quite often the capelin removes all air from the swimming bladder leading to much less echo from each fish compared to fish with neutral buoyancy. Those changes can be related to presence of predators like humpback whales but also a disturbance from vessels like light, noise from propellers or waves generated by the ships. It could be possible that heavy fisheries could affect the results of contemporary acoustic measurements, more so when the fisheries are conducted with pelagic trawl that were introduced in the capelin fisheries around 1996.

Modern equipment for conducting acoustic surveys allows one to collect data using multiple frequencies and get the frequency response. Fish with no air in their swimming bladder has, like zooplankton, an increasing back-scatter with higher frequency. Conducting those exercises can be done from the vessel at depth < 100m but at more depth it requires the acoustic transmitters to be submersed to get close enough to the target since higher frequencies attenuate faster. Getting close to the fish does also allow to evaluate the TS value of individual fish.

The results of analysing frequency response with submersible acoustic transmitters can lead to a reevaluation of the appropriate TS value to use. However, it might also show that the TS value needs to be re-evaluated in every acoustic measurement.

Looking at the SSB - recruitment relationship the results do not indicate that the approach of basing B_{lim} on the average of SSB in 1981, 1982 and 1990 (114 thous. tonnes) needs to be revised as long as the average TS value over the period is not revised. Results to change the average TS value have not been published so the old value must still be used. There are indications that the value used is conservative (too high) but it is still 0.5 dB lower than used in the Barents Sea. And the TS value to be used in autumn does not have to be the same as in winter.

The first good year class after 2003 is the 2009 year class but no capelin fisheries were allowed in the fishing season 2008/2009. The capelin fishery has been closed in 5 winter seasons 1982, 1983, 2009, 2019 and 2020. All those year classes are large compared to year classes in adjacent years, with 1983 the largest year class in the time series and there are indications that the 2019 year class is larger than what has been seen since 2009 (2020 is more uncertain). This observation leads to considerations of a more complicated effect of the fisheries on the stock than just the removal in tons.

From what is discussed above there are indications that acoustic measurements might underestimate the stock size. Two possible mechanisms are mentioned here, fish with little air in the swimming bladder and incomplete spatial coverage leading to underestimation of the stock. It can be argued that the highest measurements (if the CV is reasonable and survey does not follow the migration) would be the most correct measurement assuming the TS value used is based on capelin with neutral buoyancy.

Furthermore, the timeseries of stock size and predation are confounded. It has repeatedly been shown that the amount of capelin from acoustic measurements is not enough to account for estimated predation and catches so even though the TS value used is too high the predation could also be underestimated. How much capelin is required for cod is not very well known. Experiments with feeding cod indicate it is quite efficient (Björn Björnsson 1997). If all parameters included in the prediction of SSB of capelin were reestimated SSB would change, as would B_{lim}. The catch advice would also change, possibly increase, depending on how late the fisheries are conducted. If they are conducted early, increased predation and stock size would lead to increased catch compared to stock estimated with higher TS value.

But in the meantime, the management plan adopted is more precautionary than the one that had been used for 35 years, the difference in advice would have been 190 thous tonnes caught per year on average. The recognised failures of that plan around 1982 and 1990 did not have to do with the plan itself but rather with too high initial quota and a delay in stopping the fisheries. In early 2000, too high a TAC was allocated, probably because uncertainty in spawning stock was not recognised. Measured stock in some years was large, uncertainty moderate to high and a large part of the measured stock was subsequently removed. Developing the possibility to stop the fisheries/reduce TAC in-season might be an important factor in a management plan for capelin.

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Working document I05. Re-evaluation of the target strength and acoustic properties of the capelin stock in the Iceland–East Greenland–Jan Mayen area

Teresa Silva and Sigurður Þór Jónsson

2022-12-01

In the Benchmark, MFRI gave a presentation about the recent research developments on in situ capelin's target strength. Below we give a short overview of that presentation. During the benchmark, the need to continue to research more on the Target strength (TS) of capelin was raised. As TS is the most important scaling factor in converting the nautical area scattering coefficient (NASC) to conventional fish abundance and biomass (Blanchard *et al.*, 2012). TS has traditionally been modelled simply as a function of fish length with species-specific relationships. The general relationship is the following function

$$TS = 20logL - b(1)$$

where *TS* is target strength (dB), *L is* total fish length (cm), *b* is a constant determined by comparing the TS histogram with the size distribution of the fish (Foote, 1987). This relationship usually differs for different fish species. However, it can also be distinct for the same species, with a wide geographical spread (Rose, 1998; Guttormsen and Wilson, 2009). In Iceland, the TS relationship used is the following

$$TS = 19.1log_{10}L - 74.5(2)$$

This relationship is based on the results of the research carried out by the Norwegian Marine Research Institute more than 30 years ago on the capelin scattering properties in the Barents Sea (Anon. 1985 and Dommasnes & Röttingen 1985). Studies have noted the need for *in situ* target strength measurement to reflect the capelin in their natural habitat (Jørgensen, 2004). This TS-length relationship is a crucial element in the stock assessment of capelin with significant implications in stock assessment. Therefore, it is vital to study the acoustic properties of Iceland-Jan Mayen-Greenland, one of the world's most extensive pelagic fish stocks (Vilhjalmsson, 1994; Gjøsæter, 1998). The behaviour of the capelin can significantly affect the measured resonance (Jørgensen, 2004). However, one of the most important factors is that the beam's depth can significantly affect the measured resonance (Jørgensen, 2004; Fässler *et al.*, 2009). Therefore, one of the main goals is to assess *in situ* strength of single targets, using narrowband and broadband measurements of capelin analyzed with respect to depth dependence, gonad status and fat content. The project has the following **research questions:**

- Are narrowband (CW) mean TS-length assumptions used currently in stock assessment correct?
- Is there a significant variability in capelin backscatter that should be accounted for instead of using overall geometric mean?
  - Depth/pressure dependency
  - Seasonal dependency
  - Body condition dependency
- Can broadband (FM) measurements increase the quality of acoustic estimates?
  - FM backscattering properties of capelin
  - Are measurements in FM frequency channels comparable to CW measurements?
- Can the high-density FM single target detections give full count of targets in the sampling volume?

Objective

We aim to use the submersible echosounder WBT-Tube (Simrad EK80; ES38 18DK-split and ES120-7CD kHz) within the capelin project so to provide high-resolution acoustic data (35 to 45 and 90 to 170 kHz, respectively, for broadband) of capelin schools down to at most 500 m. The objective is to evaluate the influence of physiology and behaviour on the in-situ target strength measurements of capelin. The main goals are, therefore, to analyze in situ target strength measurements of capelin with respect to depth, gonad status, fat content and behaviour (swimming angle of the fish).

Preliminary results

Below we show the limited number of sampling deployments conducted in this project so far (Table 1). Preliminary results show a change of capelin target strength (TS) with depth using narrowband and broadband data (Fig. 1). Here, we have analysed the TS data collected last year with the submersible echosounder complemented with the ship hull mounted acoustics when capelin schools were found in surface (at depths <50m). The single TS data were extracted in LSSS 2.13.0 using SED algorithm and following the guidelines from several research sources (Ona, 1999; Jørgensen, 2004; Kubilius and Ona, 2012; Agersted *et al.*, 2021). Afterwards, single TS data were filtered and cleaned by 1) selecting targets stronger than -70dB, 2) selecting targets within the central part of the beam (out to ~5 degrees off-axis) and 3) at a distance of 15 to 30 m from the transducer and 4) any outliers at each depth strata were evaluated per acoustic mode (CW or FM) (Ona, 1999; Kubilius and Ona, 2012). Preliminary results show that the beam-compensated TS (TSC, dB re m^2) data collected with narrowband were highly variable in contrast to the data collected in broadband (Fig. 1). The current TS data is somewhat limited, especially for the deep stations (Table 1), and thus the TS-Length relationship that we currently have is rather poor (Fig. 2). The in situ TS data show a lower TS relationship than the one used in the current acoustic assessment (equation 2). However, the TS relationship shown here (Fig. 2) is close to the previous average in situ TS of capelin estimated to be -56.9 and -56.6 dB (for 11.5 and 14.5 cm) by Halldorsson and Reynisson (1983).

Table 1. Stations deployments in the past cruises.

Season	*Cruise*	*Depth range [m]*	*Nr WBT-TUBE stations*	*Nr hull-mounted acoustics stations*
Autumn	A14-2021	<100		2
	B10-2021	<100	1	2
		100-200	1	
	A10-2022	>200	2	
Winter	A01-2022	<100	1	3
		>200	1	
		100-200	1	
	A02-2022	<100		1

>200	2

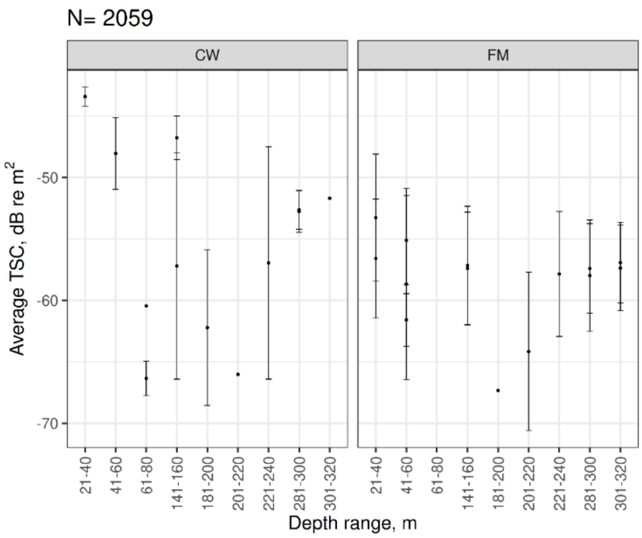

Figure 1. The average Target Strength beam Compensated (TSC, dB re m^2) in narrowband (CW) and broadband (FM) of capelin schools change with depth (m) of the schools. TS measurements were collected with the submersible echosounder (WBT-TUBE) during the last surveys (see Table 1 for more information).

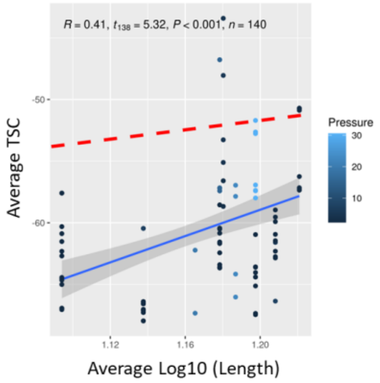

Figure 2. Preliminary results of the relationship of average Target Strength beam Compensated (TSC, dB re m^2) and the average total length of fish in samples from stations with TS measurements (Log10 transformed) in blue. The current TS-Length relationship used in the stock assessment $TS = 19.1log_{10}L - 74.5$, is presented by the red dash line. The color legend shows the pressure (as atmospheric pressure) at which the TS measurements were collected.

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Working document I06. Capelin Fisheries in the Iceland-East Greenland-Jan Mayen area.

This working document describes some aspects in the development of the capelin fisheries, mostly the winter fisheries. Things that could be relevant to the benchmark is CPUE in the pelagic trawl fisheries, possibly as a measure of the amount of capelin in the area and in the case of 2022, providing support for the winter survey estimate rather than the high stock values surveyed in the autumn . Observed and predicted NASC from vessels with calibrated echosounders, fishing capelin with a pelagic trawl could be one way to get TS values as described near the end of this working document.

Capelin were until 1998 only caught by purse seines, but after that a significant proportion of the catches were taken with pelagic trawl (figure 1). This figure is based on the Icelandic landings database but catches by other countries are nearly completely caught with purse seine (except for some Greenlandic catches in recent years which were caught by pelagic trawl). The distribution by month would also change if other nations were included; Norwegians are for example not allowed to fish south of 65th degree north so they do not contribute much to the catches in February and March.

Looking at catches by month (figure 2) most of the trawl fisheries are conducted in January and February (early February). The catches by month would increase if foreign catches which are all purse seine fisheries were included, but they are important part of the summer, autumn and January fisheries.

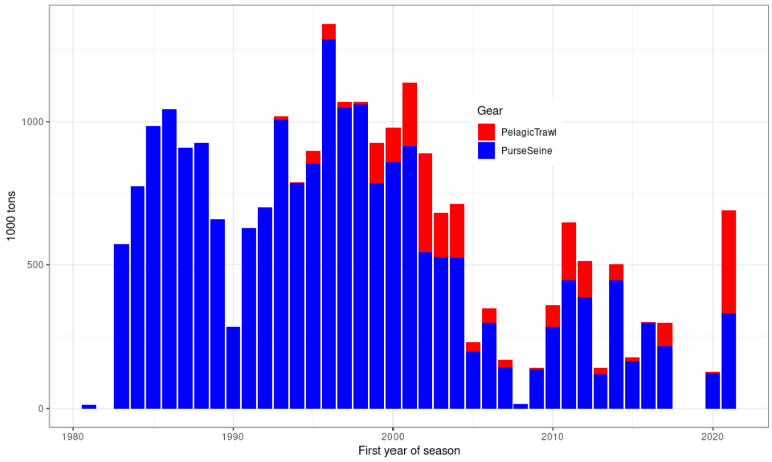

Figure 1: Capelin catches by year and gear

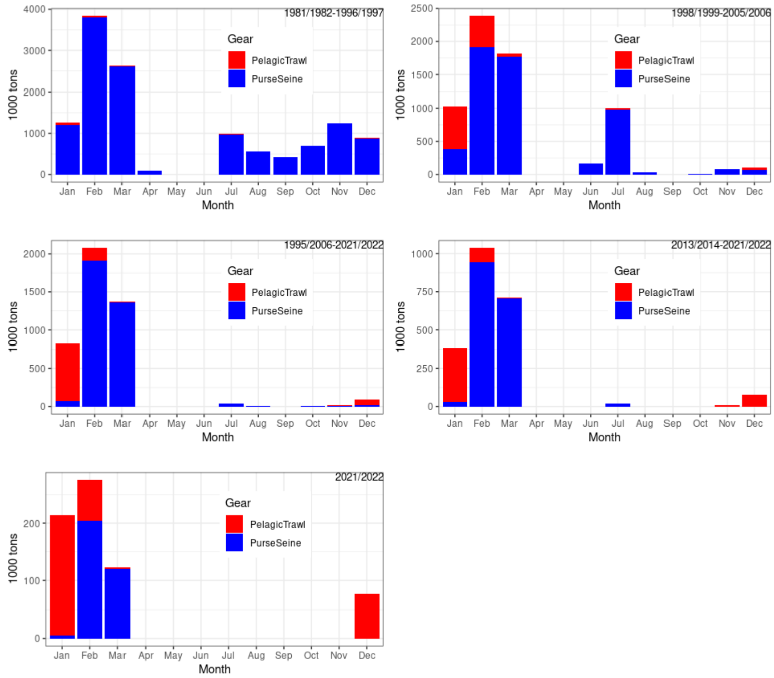

Figure 2: Catch by month and gear over different periods

February is on average the month with most of the catches with March in second place. The highest landings in a single month are close to 400 thous. tonnes (figure 3). The January catches in 2022 are relatively high compared to average January. The Icelandic fleet did not catch the allocated quota in 2022 as the catches in February and especially March were much less than would have been expected. Weather could have been a factor since winter 2022 was stormy. Another factor is that only one fish meal factory is left in south-west Iceland, in Akranes 50 km from Reykjavík , so the distance from fishing areas to landing sites is relatively large. The factories in Reykjavík and Helguvík (close to Reykjavík) closed in 2009 and 2019.

Another possible explanation is that the capelin spawned relatively early in 2022. Looking at the landings by week 1995-2022 does not show much trend, but in some years the season extends 1-2 weeks longer than in others.

In some years the fisheries started late, for example in 1998. In recent years the late start is related to small quotas that are used for the most valuable fisheries i.e for roes.

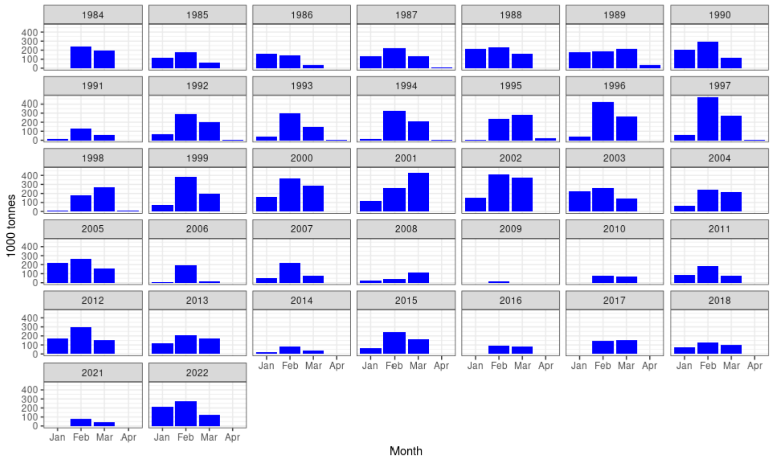

Figure 3: Capelin landings by month taken from lods (the landings database in Iceland) and before 1993 data from Fiskifélag (the predecessor of the Fisheries Directorate)

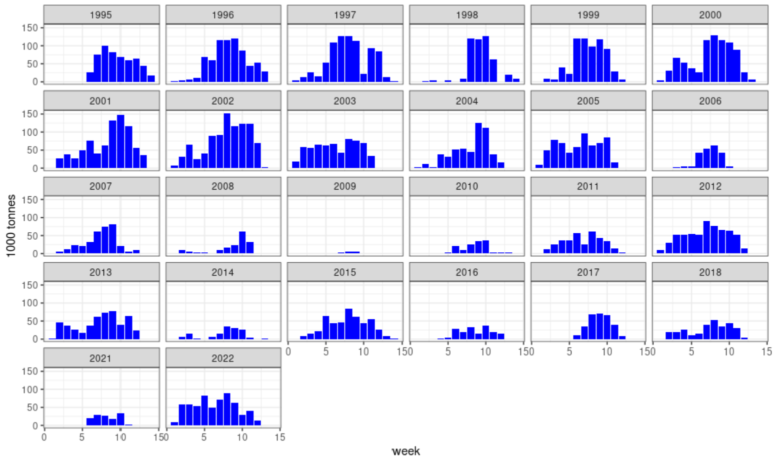

Figure 4: Capelin landings by week, for reference week number 10 is 4th - 11th of March

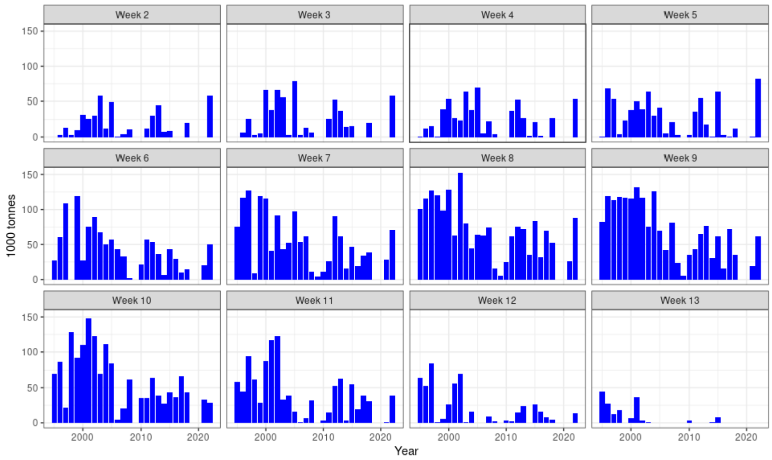

Figure 5: Capelin landings by week, for reference week number 10 is 4th - 11th of March

The catches in January have since 2010 mostly been taken by pelagic trawl (figure 6). In the nineties catches of capelin in January were low but increased after 2000, possibly due to the pelagic trawl. In the early 2000's the summer/autumn fisheries reduced compared to the years before, possibly leading to increased January fisheries.

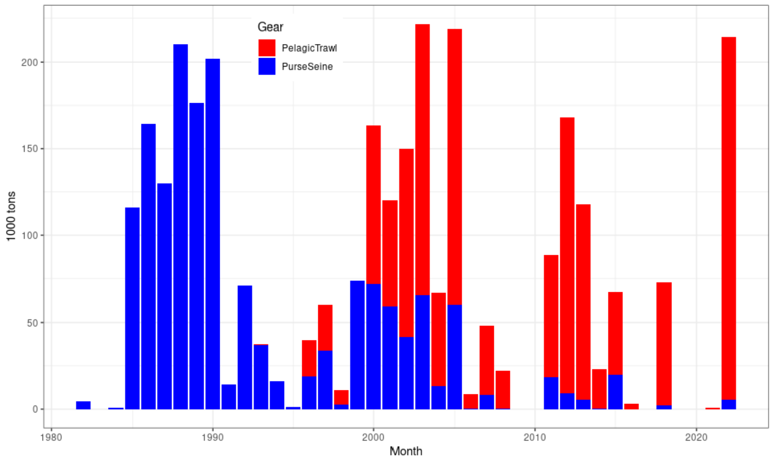

Figure 6: Capelin landings in January

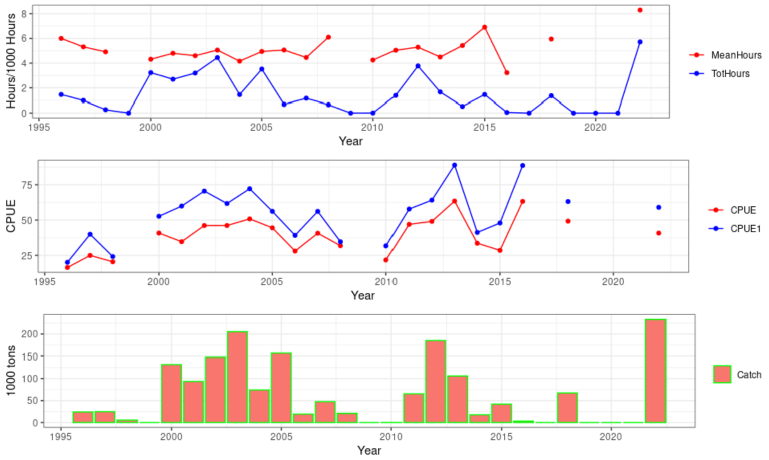

Figure 7: CPUE, total hours trawled, average number of hours trawled in January and first week of February (upper panel). CPUE1 (blue) is Catch/Hours for each haul but CPUE (red) sum(Catch)/sum(Hours) (middle panel). Total catches by year (lower panel).

The pelagic trawl fisheries in January 2022 were the highest ever but the trawling effort was really high and CPUE relatively low (figure 7). The average number of hours trawled was 8.3 and has never been so high. The traditional CPUE measure is also relatively low (CPUE in the middle figure). The results do therefore show that the fisheries were not doing too well.

A closer look at the CPUE for the years 2012 and 2022 will be done, but those 2 years have the most fisheries in pelagic trawl in January (figure 7).

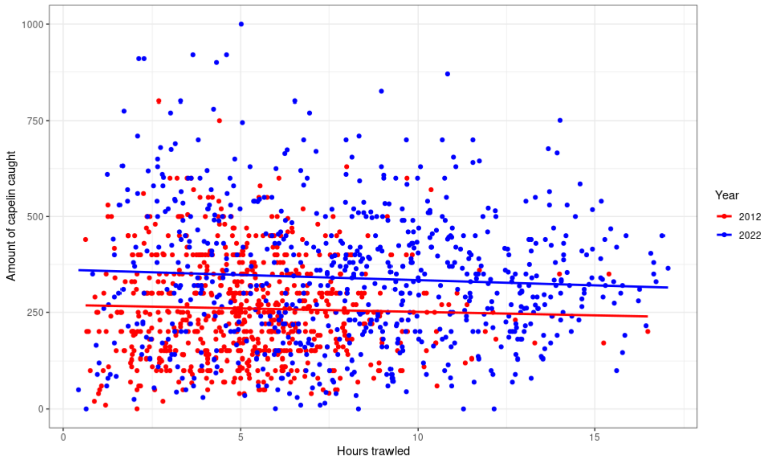

Figure 8: Catch of capelin vs hours trawled in January and first week of February 2012 and 2022

Figure 8 shows that the amount of capelin caught in a haul is independent of hours trawled or reduces slightly with the numbers of hours trawled. CPUE based on hours trawled does therefore decrease with hours trawled. The captains stop trawling when the catch-sensors in the cod-end of the trawl indicate "enough" so higher catch rate means shorter hauls.

The average number of hours trawled was 5.29 in 2012 and 8.30 in 2022 . CPUE compiled the traditional way $\frac{\sum C}{\sum E}$ was lower in 2022 than 2012, 28.1 vs 35 tons/hour, respectively, even though catch for a given numbers of hours trawled is higher in 2022 than 2012 (Figure 8).

The estimated biomass in 2012 was 1014 thous tonnes but 904 thous tonnes in 2022, less than the difference in CPUE. In 2012 there were 2 surveys conducted in January both giving approximately the same result, taking catches in between into account. In January 2022, two surveys gave very different results.

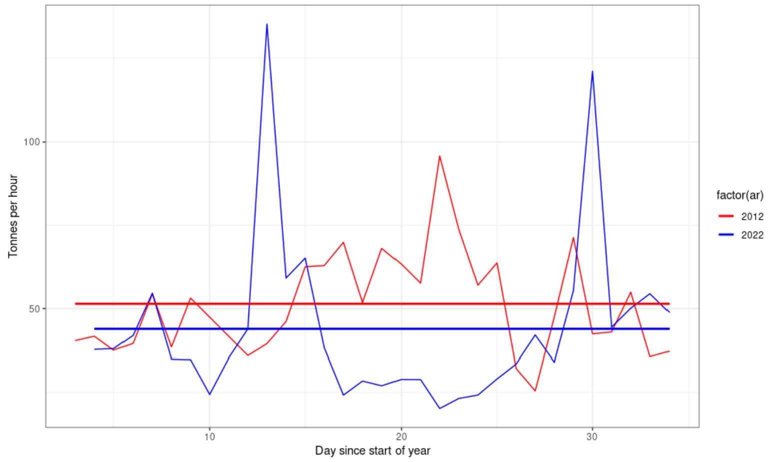

Figure 9: CPUE per day in January and 1st days of February 2022 and 2022

CPUE per day is shown in figure 9. Here the CPUE 2012 is less variable than in 2022 and usually higher.

Small check if the size of engine matters is shown below (figure 10) indicating no relationship. This result would be expected as lack of power is probably not a major problem.

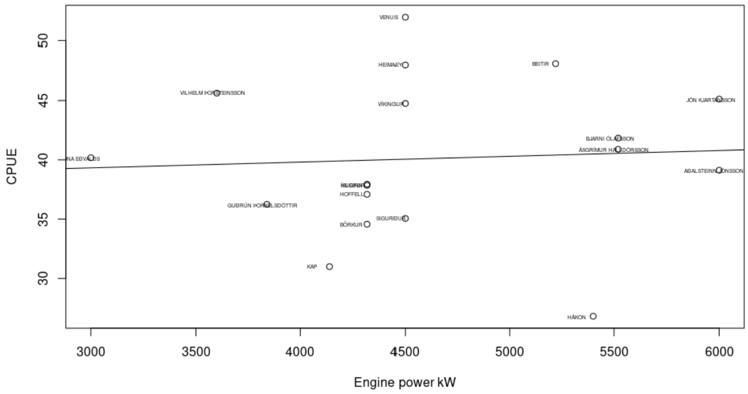

Figure 10: CPUE in January 2022 calculated as sum(capelin)/sum(hours trawled) as a function of engine power.

Since catches of capelin by pelagic trawl started around 1996 there have been speculations about side effects of those fisheries. There are number of possible effects.

1. Mortality of capelin escaping the trawl.

2. Disturbance to migrations.

3. Reduced acoustic backscatter i.e. the capelin gets rid of air in the swimming bladder, migrates or increases its depth.

Those factors cannot easily be separated. Reduced acoustic back scatter means that the capelin are not "seen" so migrations cannot be monitored. Getting rid of air in the swimming bladder could be a response to predators like marine mammals but has also be noticed when a vessel turns its lights on. The same applies to disturbance from vessels, both noise from propellers and disturbance when the vessel is sailing.
The capelin fisheries by pelagic trawl in January - February 2022 covered an area of $5 - 10000 km^2$, in each day only a fraction of this area ($\sim 1000 km^2$) was covered. The number of vessels participating each day varies from 10-20 (figure 11) and the number of hauls registered each day is usually 1 to 4 per vessels (table 1) . 10 - 20 vessels does not seem to be a lot but the trawls are large and each vessel can tow 25 miles/day.

Table 1: Number of tows per vessel per day in the capelin fisheries in January-February 2022

Number of tows per day	Frequency

1	221
2	168
3	45
4	16
6	1
7	1

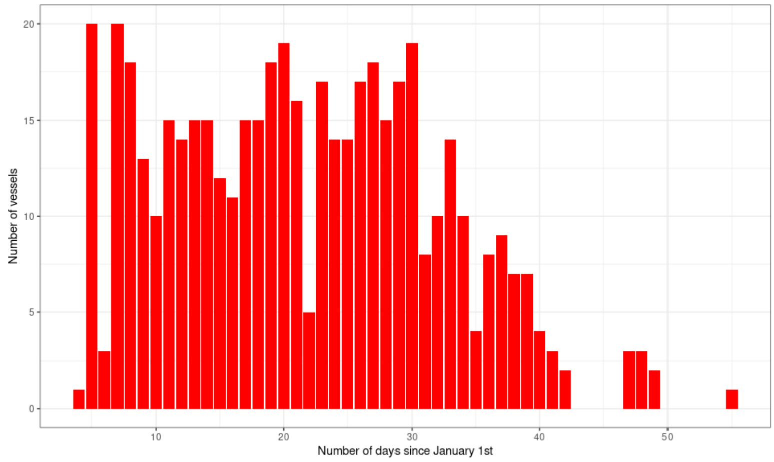

Figure 11: Number of vessels participating in the Icelandic capelin fisheries in January - February 2022

Getting the logbooks from other nations would be informative. The Norwegian and Faroese vessels are not allowed to use pelagic trawl and getting information on catch rates from purse seines could give valuable information.

Converting catch rates in pelagic trawl to NASC value is an interesting exercise that requires a number of assumptions that are listed below.

1. The trawl catches all the capelin in the water column over width of 20m.
2. Mean weight of capelin is 23g and mean length 16cm. Those values are assumed to apply to all the capelin.

3. In the survey all registrations with NASC > 10 are selected.

Assumption 1 is much more questionable than assumption 2. The trawl is designed so the transition from 60mm to a much larger mesh size occurs sharply. Opening of the trawl at the 60mm boundary could be described as an ellipse with axis 20m horizontally and 10mm vertically. Some hearding is excluded by this but letting a trawl with 10m vertical opening take all capelin in the water column is overestimation. Further work will be needed to get better estimate of the trawl's catchablility.

The results, (figure 12) show that the average NASC for the fleet is 7700 but 701 for the acoustic values. The strategy is different, the fleet uses sonars and bends towards schools that they see while the acoustic measurements are supposed to proceed along predetermined transects.

The NASC values from the survey are quite patchy. 9 of 5000 values are > 25000, excluding them from the mean reduces the mean by 10% and they are distributed all over the area. Therefore, CV of the survey is estimated relatively low.

If those two approaches can be compared in some sensible way needs to be analysed. The first step is to get data from the Icelandic vessels that have calibrated echosounders, first to see if data are available for last season and also arrange sampling in this season.

When doing this kind of exercise, the characteristics of the trawl need to be measured, what is the effective width and height of the trawl and how large a part of the capelin school escapes through the mesh.

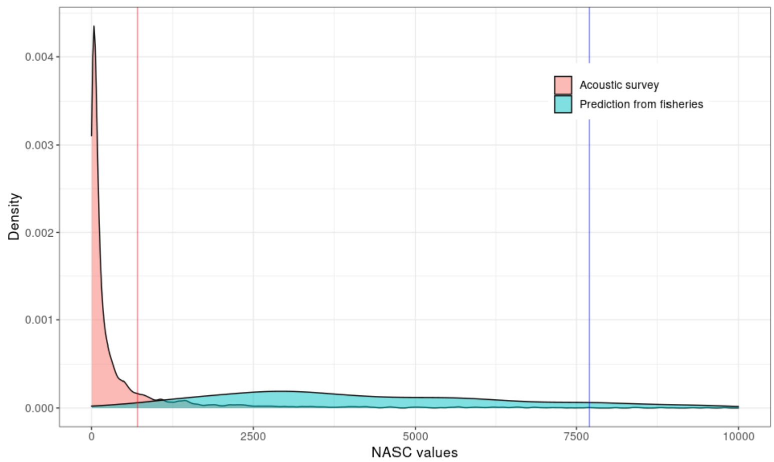

Figure 12: Conversion of CPUE of the capelin fleet to NASC. Results based on width=100m, speed 3 knots and that the trawl covers the whole water column

Histogram of NASC values in January 2012 and 2022 were compared (figure 13). The 2012 values are the summary of 2 surveys in the period 5th-24th of January while 2022 is one survey from January 25th to January 31st (reflects later arrival of spawning migration). Average NASC was 955 in 2012 but 701 in 2022. The histogram is similar, the ratio of means 0.71 but ratio of medians 0.74. The tails (NASC > 25000) had more effect in 2012.

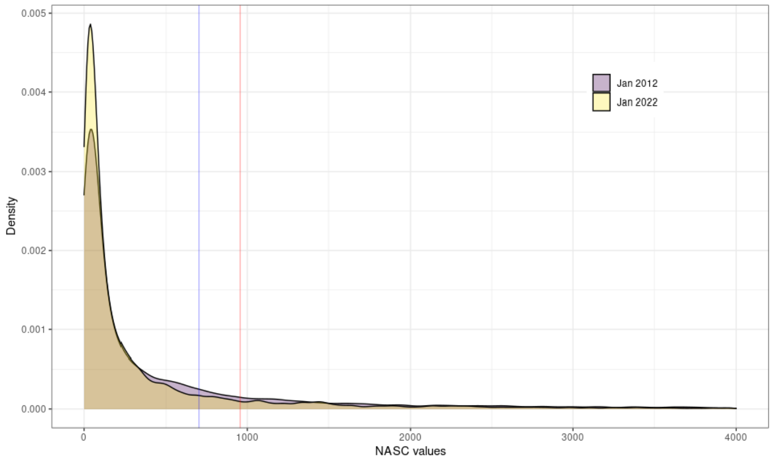

Figure 13: Distribution of NASC values in 2012 and 2022

Working document I07. IEGJ capelin, experience with new management plan 2015/16 to 2021/22.

Sigurvin Bjarnason and Höskuldur Björnsson

2022-12-05

The management plan for Icelandic capelin that was evaluated by ICES in 2015 has now been used to generate advice for 7 years, the seasons 2015/2016-2021/2022. Compiling the advice has not always been straight forward and in many years the survey effort has been considerable, partly to reduce the estimated uncertainty in the acoustic measurements. To put the numbers below in context, average catch in fishing seasons since 1975 has been around 700 kt and the escape biomass in the old HCR was 400 kt while B_{lim} in the new management plan is 150 kt. With the new management plan, measuring 500 kt can be enough to start the fishery if CV of the survey is low.

Stock in this report always refers to the mature part of the stock.

For each survey a large number of bootstrap replicas $(N_r)$of the spawning stock are generated. When N surveys are averaged, they are averaged replica by replica. $I_i = \frac{\sum_{j=1}^{j=N_r} I_{j,i}}{N}$ where i is the number of the replica. If surveys are considered to represent different parts of the stock, they are in the same way summed replica by replica.

#2015/2016

Autumn survey 2015 was conducted in the latter part of September, measuring 550 kt of mature capelin, leading to a starting quota of 44 kt. A second survey from 3-21 of January estimated 675 kt of mature capelin. The TAC was based on the January survey only. An alternative would have been to take the average of the autumn and January survey but stormy weather in the autumn survey was used as justification to only use the January survey. The TAC was 173 kt but would have been close to 275 kt using the old HCR. Surveys were attempted without success in November and February.

#2016/2017

This year turned out to be rather special. The autumn survey in late September 2016 indicated that the stock size was only 137 kt. The stock was again measured 11-21 Jan by 3 vessels leading to a stock size of 446 kt. 11-15. Jan the stock was measured from east to west giving 398 kt and from west to east 16-21 Jan giving 493 kt. Migration of capelin in this period is usually considered to be from west to east so taking the average is appropriate.

The MFRI wanted to stop survey effort at this stage, but the industry wanted to continue. A survey was then conducted in the area north of Iceland from 3-11 of February by 3 vessels. The mature part of the stock was estimated 815 kt, much higher than in any of the preceeding surveys. Age 4 (the older age group in the mature stock) was 39% of the stock in this February survey but 25% in the January surveys. The distribution of the stock north of Iceland was also rather unusual for this time of year when the capelin migration is usually in the southeast. The TAC was based only on the February survey and was 299 kt and would have been 415 kt with the old HCR. Age distribution of the catches indicated a high proportion of the older ages as seen in the February survey.

#2017/2018

This year the advice was based on an average of 3 surveys, The first one was an autumn survey in September 2017 where the stock was estimated 945 kt with CV of 0.30. The stock was measured by 3 vessels 16-31st of January 2018 and estimated to be 801 kt. The January measurement is really an average of 2 measurements from 17-22nd and 25-31st of January. Mean of the first measurement was 845 kt but CV was high (0.41). Mean of the second measurement was 764kt and CV 0.19. As all the acoustic measurements indicated similar stock size, the TAC was based on the average of all 3 surveys, a mean of 853 kt, CV 0.18. The final TAC was 285 kt but would have been around 500 kt based on the old HCR (using the autumn survey).

#2018/2019

The autumn survey 2018 was conducted in September by 3 vessels giving stock size of 238 kt. 5 winter surveys were conducted in January - March 2019 with survey 2 - 5 giving stocks size of 200, 300, 170 and 220 kt. Survey 1 was a scouting survey in early January. Surveys 2 and 3 were conducted north and east of Iceland 22-30th of January and February 1-8th. Surveys 4 and 5 were conducted south and southwest of Iceland in late February and early March. There was relatively good consistency of the survey results in terms of biomass of mature capelin in 2018/2019. The last 2 surveys were conducted in the warm sea which is not a recommended procedure.

The results of all surveys led to an advice of 0 so there were no fisheries in the 2018/2019 fishing season. Average biomass of the autumn survey and surveys 2-3 in winter was 259 kt with CV of 0.17. CV of the 3 surveys was 0.26, 0.44 and 0.24.

#2019/2020

The autumn survey was conducted in September - October 2019 by 2 vessels. The mature biomass was estimated 186 kt with CV of 0.31 and the number of immatures was estimated to be 82.6 billion, giving a initial advice for the next season (2020/2021) of 170 kt. The result was questionable because most of the index was coming from a limited area as shown with a high CV (0.44)

3 acoustic surveys were conducted in winter

1. 13th - 25th of January by 3 vessels proceeding from E-W indicating 65 kt stock.

2. 1-9th of February by 3 vessels proceeding in from W-E and E-W indicating 262 kt stock.

3. 16-22nd of February north and northwest of Iceland, measuring 50 kt stock.

The first two surveys covered all the area from the southeast to northwest part of Iceland measuring no capelin in the east and southeast migrating the "normal" route. The last survey was to look for spawning migration taking the western route or capelin spawning in the north.

#2020/2021

The autumn survey in 2020 was conducted in September by 2 vessels. The mature biomass was estimated 344 kt which resulted in 0 catch for the coming winter season. Like the previous year, the immature estimate was high (146 billion, CV 0.23), resulting in an initial advice for the following 2021/2022 season (400 kt). There was some sea ice covering the area where most of the mature capelin were measured, indicating that the autumn survey did not cover the whole stock.

Because the initial TAC from autumn 2019 was revised, a decision was made to add a December survey in 2020. The results from it were 487 kt of mature capelin which gave a TAC of 21.8 kt. Mature capelin had already arrived east of the Kolbeinsey ridge, indicating an earlier arrival than in previous years.

In the winter surveys 2021, the first survey was 4-9th of Jan. using 4 vessels. It did not add much to the December survey other than that the capelin had moved further east but not further south.

17-20th of January a measurement was conducted by 2 vessels southeast of Iceland measuring 401 kt, of which 325 kt were south of 65th degree north. A 4th survey was done by 4 vessels (2 research vessels and 2 calibrated fishing vessels) from January 26-30th covering areas north and east of Iceland. The result was 415 kt of which 325 kt were north of 65th degree N.

Using the fact that mature capelin east of Iceland migrate south, capelin south of 65th degree in the first survey and north of 65th degree in the second survey were added resulting in a total SSB of 650 kt. The reason for not measuring all the area at once was short weather windows (an important concept in winter surveys).

#2021/2022

The autumn survey in 2021 was conducted in September and resulted in a record high mature biomass of capelin 1833 kt. and a very high immature estimate (131.5 billion, CV=0.15).

The following winter (2022), the fisheries had already started when the surveys were conducted. The goal was to start surveying before the first mature capelin would reach the thermal front southeast of Iceland (where they often get lost). Tracking the fisheries, a survey was conducted 18-25th of January proceeding against the assumed capelin migration, resulting in 404 kt stock. A second coverage was conduced 25th of January - 2nd of February proceeding in the most likely direction of migration resulting in 903 kt stock. Changes in distribution of the stock between the surveys were not large. In the first survey the stock had not quite reached the thermal front south-east of Iceland but in the second survey the highest records were there, but there was also capelin north of Iceland. Some capelin might already have migrated into the warm sea and new schools probably arrived north of Iceland. On this basis the second survey was considered to give a more realistic picture of the stock, even though it proceeded in the most likely direction of migration.

The difference between the second winter survey and the autumn survey was large: 930 kt (1833 vs 903 kt). Catches between the surveys were estimated 285kt, reducing the difference to $930 - 285 = 645kt$. The large reduction in stock size between summer and winter far exceeded anything seen in the series. The final advice for the fishing season 2021/2022 was 869 kt based on the average of autumn and second winter surveys but the catches were estimated to be 688 kt. There are indications that the winter surveys gave a more realistic picture of the stock on the Icelandic continental shelf than the autumn survey, and those contradictory results will be analysed in the benchmark.

Annex 5: External reviewer report

External Reviewer Report

Hannah Murphy (co-chair), and Mathieu Boudreau and Alejandro Buren acted as the external experts for the WKCAPELIN 2022 benchmark of the Barents Sea and Iceland-East Greenland-Jan Mayen (IEGJM) capelin stocks. We evaluated the methods used for the assessment of both stocks from 21-25 November, 2022.

Assessment working documents and supporting materials were distributed prior to the benchmark meeting. Additionally, a WebEx meeting was organized prior to the in-person meeting to provide a general overview of the assessment approach for both stocks. We appreciate that these materials were made available before the in-person benchmark meeting. A suggested improvement would be to provide finalized working documents at least a week prior to the beginning of the benchmark meeting to allow sufficient time for proper review. We also recommend that these types of preparatory efforts continue in the future as they improved the efficiency of the review process and the benchmark workshop.

We commend the workshop participants for their efforts during the benchmark process. The assessment team was asked to provide many additional analyses during the meeting. Their response to the requests was helpful in furthering our understanding of the assessment models and were successful in bringing useful information to the management process.

The sections below summarize the discussions during the meeting and the recommendations made by the panel regarding these stocks.

General approach to provision of management advice

Both fisheries target the maturing population in their spawning migration routes. They are both managed with a similar target escapement management strategy. Escapement strategies are harvest control rules (HCR) which are suitable for stocks with highly variable stock size and recruitment, allowing for high catches in good years while protecting the stocks in poor years. The standard format for such a rule would be that there is a 95% probability that the spawning stock biomass (SSB) is likely to remain above Bescapement after the catches are taken, where Bescapement is the biomass of adults that survive natural mortality and fishery to breed. For fish such as capelin, where there is a high spawning mortality, Bescapement may be set to Blim. In this case, the rules for the Barents Sea and the IEGJM capelin stocks are in this form, and both are based on HCR previously adopted by ICES. The meeting was tasked with evaluating if the existing HCR continued to be precautionary, and therefore could continue to be used as the basis of ICES advice. Hence, the different sets of data, equation formulations and assumptions considered for the calculation of the SSB values used in the HCR (i.e. the SSB of the stock during spawning time) were reviewed. In summary, the general approach for both stocks is to estimate the abundance-at-age of mature capelin in the acoustic surveys and make projections of the SSB from the time of the survey to the spawning season by including natural mortality rates and predation mortality. Estimates of abundance for both stocks are assumed to be absolute (i.e., catchability = 1). This more than likely is not realistic. However, this assumption is believed to be precautionary as the survey coverages are not complete.

Barents Sea capelin

1. Abundance estimates

Estimates of abundance for the Barents Sea capelin stock are made annually based on acoustic-trawl monitoring data. Since 2004, the data collection has been done as part of the joint Russian/Norwegian Barents Sea Ecosystem Survey (BESS) conducted in August-October. This acoustic survey is also supported by pelagic and demersal trawls at fixed and non-fixed positions.

1.1 Swept area estimation from bottom trawl

Large mature capelin are caught in the demersal trawls, i.e. in the acoustic dead zone. The length composition from the demersal and pelagic trawls differ, suggesting that there is a component of the stock that is not represented in the acoustic estimates. There were discussions on how to best deal with this issue in terms of how this component of the stock should be summed to the capelin abundance estimated with the acoustic survey. A proposal was presented on how to combine the two estimates, but it did not address how to combine the metrics of variability from the two components (demersal and pelagic). The suggestion is simply to add the numbers by age and length group estimated from bottom trawls to the numbers by age and length group estimated by acoustics. This method is simplistic and rests on several assumptions:

- None of the capelin individuals caught in the bottom trawl were detected acoustically.
- None of the individuals detected by acoustics were caught in the bottom trawls.
- There is no herding effect by sweeps and doors (sweeping width = 25 m).
- The fishing height of the trawl is the vertical trawl opening (ca 4 m).
- There is no selection of capelin in the trawl.

The abundance of demersal capelin is much lower than the abundance of mature pelagic capelin in years of high capelin abundance, but they may represent a non-negligible proportion (~10%) of the stock in years when a low abundance of pelagic capelin were found. Therefore, it has the potential to overestimate the value of Blim. Unfortunately, the impact on Blim of including demersal capelin in the total abundance estimate was not carried out as there are challenges on how to proceed with data before 2004 when the ecosystem survey began. The panel recommended to not include demersal capelin at this stage and to work towards a review to include them. The panel also agrees that there is a significant bottom capelin component, and in principle they should be included in the total abundance estimate. However further work is needed to:

- account for potential double counting in the bottom trawl and acoustic surveys,
- deal with outliers from schools showing up in the trawl survey,
- estimate the uncertainty in the combined demersal-pelagic biomass,
- validate the average value projected back in time against the early data from years where it is available

Finally, the panel recommended that a future review should be done before incorporating the bottom capelin component into the management framework since it would require the re-evaluation of factors such as Blim.

1.2 Autumn Survey: Selection of station for the allocation of acoustic data

Biological data obtained from trawl hauls is needed to estimate capelin length distributions to transform the acoustic backscatter to a biomass estimate. Currently, there is no standard procedure to do this transformation. During the benchmark meeting, three different sets of data that can be used for the transformation were proposed:

- Data from the station selection used for the original estimate.
- Data from all stations with capelin catch selected including demersal trawls.
- Data with only target hauls selected.

The different data allocations showed systematic differences in the resulting biomass estimates. For example, the capelin sampled in the demersal trawl are typically not observed in the echogram and are therefore not representative of the capelin recorded acoustically leading to over-representation of large capelin. The panel agreed to keep the current procedure for the selection of stations for the original estimate. The panel also recommended that this issue should be revisited in a future review process that would also address the swept area estimation from the bottom trawl survey.

1.3 Pre-Spawning survey

A winter trawl-acoustic survey monitoring the pre-spawning capelin has been carried out from 2019 to 2022 to potentially reduce the uncertainty in the biomass estimates of mature capelin used in the assessment and improve the accuracy of the TAC advice. Even though some issues have been identified such as the absence of coverage in the Russian waters and the timing of the survey, some useful insights were highlighted:

- The design and vessels used provided efficient monitoring.
- The biomass estimated in the winter survey overlaps the lower range of the confidence interval of the modelled stock projection based on the autumn survey and mortality.
- There is significant dynamics in the spatial distribution of spawning capelin.

The panel agreed that some work still needs to be carried out so the information gathered during this survey can be used to set TAC. The abundance is likely underestimated given the partial coverage of the survey and therefore poses challenges to extrapolate to absolute abundance estimates. However, estimates obtained through the spawning survey could be useful for management advice if something goes wrong with the autumn survey like setting an initial precautionary quota and then potentially increase or reduce it based on the spawning survey. Due to current political uncertainties, the panel recommended to keep the current management framework without the inclusion of the spawning survey for quota revision. However, the spawning survey is used in tuning the parameters in the assessment model and should be one of the data sources considered in the event of another failure of the autumn survey.

2. Coefficient of Variation for the autumn survey estimates

In the current assessment of the Barents Sea capelin stock, a fixed sampling variance expressed as Coefficient of Variation (CV) of 0.2 for all age groups is used in the input for the maturing stock in the spawning biomass forecast. During the benchmark meeting, annual age-specific CV for the series 2004-2021 were presented to assess if they should be used in the stock forecast. Results indicated that CV at age vary from year to year likely reflecting differences in the patchiness of schools of capelin distribution, but also differences in the sampling effort. The actual fixed CV does not reflect those results and the use of annual CV-estimates was proposed for the spawning stock projection in the future.

There were several requests during the meeting that were addressed by the Barents Sea capelin team:

- Evaluate how CV estimates by year change with abundance for age groups 1-4. Overall, there is a decreasing trend with increasing abundance.
- Assess the effect on the forecast of changing the CV by age (while keeping other parameters constant). The catch advice when the estimated survey CV was high (year 2009) would have been reduced from 240 000 to 77 000. When applying an average CV based on the years 2004-2021, the catch advice would have changed to 200 000 tons.
- Verify the sensitivity of the CV estimate to the number of bootstrap replicates. There was little effect on the estimated CV of age groups 1-3 of increasing number of replicas above 1000. For the CV of abundance of 4-year-olds, the estimate did not stabilise with increasing number of replicas up to 10 000. It should be noted that the abundance of 4-year-olds was low.

Two concerns were raised during the meeting against the use of an annual CV estimate in the assessment. The first regards whether the CV is a good estimate of survey uncertainty (that is, sampling uncertainty), or whether it mostly tracks noise. For the time series back to 2004, there is a slight negative trend in CV over time which coincides with an increased survey effort. There are also indications of lower CV with higher abundance at age which one would expect if distribution area increased with increasing abundance and decreasing patchiness distribution. The second concern was related to very low CV (around 0.1) observed in some years. The question is whether the CV in such cases represents a major component of the total uncertainty or whether other sources of uncertainties contribute more to the total uncertainty than the sampling variance. The benchmark meeting group did not have an answer to where the lower bound of a CV realistically reflecting survey uncertainty would be, but the opinion of the group was that a CV of 0.1 was very low and might be an under-estimate of total uncertainty.

The panel recommended to use 5-year moving average CV at age for the autumn survey and update the values between benchmarks. If there is an expert judgement that the autumn survey is of unusually poor quality for a given year, then the annual CV estimates for that year should be considered, as these would lead to precautionary catch advice. Strong effort should be placed on finding a precautionary method to use the annual CVs, as these account for years of poor survey coverage and would correctly allow for improvements in survey quality to be associated with increased catches. It was also recommended that 10000 replicas are used in future assessments, since the cost of running this is low.

3. Maturation parameters

The estimate of stock abundance is divided into a maturing and an immature part assuming that the probability to mature and spawn is dependent on length only. At present, the proportion of the stock that is mature is estimated using the following formula:

$$m(l) = \frac{1}{1 + e^{4*P1*(P2-l)}}$$

where *P1* is fixed at 3.5, and *P2* is resampled with a mean of 13.89 and SD = 0.075. There is an inconsistency in the reporting as a cut-off of 14.0 cm is used to calculate the historic values of the maturing stock. A cut-off of around 14 cm is consistent with catch and spawning survey data. There were discussions that a function with a steep slope and parameter *P2* of around 14 cm should work well for these data. There were also discussions that this function may have varied over time, but some evidence was shown suggesting that this function has remained fairly stable over time. There was a request to estimate both parameters simultaneously, and to compare the estimated length distribution for the autumn survey to the length distribution from the catch.

The panel recommended to use the existing cut-off of 14 cm (in the model as well as in the catch and survey data), but also recommended to continue this research and attempt to move to a fully optimized maturation function for the next benchmark.

4. Projection to assessment date

The spawning stock biomass is projected ahead from October 1st (end of survey) to April 1st (spawning time). The resulting biomass is based on the maturing part of the stock in the autumn survey that is reduced by natural mortality and predation by immature cod. In the period between the autumn survey and the first of January, the natural mortality is assumed to be variable by year and is calculated based on survey data. In the period from January 1st to April 1st, the predation mortality is estimated with the abundance of the immature cod stock component that overlaps with mature capelin and is considered large enough to prey on maturing capelin. It is assumed that there is no growth in capelin length or weight during the period from October to April.

4.1 Survey mortality

Survey mortality is used to estimate natural mortality at age in the autumn with the following equation:

$$M_a = -\log\left(\left(N_{a+1,y+1} + C_{a+1,y+1}\right) / NI_{a,y}\right)$$

Where M_a is the natural mortality from a given age *a* to the next year *y, N* the number of capelin in the autumn survey, *C* represents the catches of immature capelin by the fishery and *NI* is the number of immature capelin in the autumn survey.

In the current assessment the mortality is estimated year by year from age 1 to age 2 and from age 2 to age 3. Replicates (N=1000) from the estimation are used in the practical assessment for the annual autumn forecast. Mortality estimates from the years 1980-1985, 1990-1993 and 1997-2002 have been selected and used in the projection model of the biomass. In each simulation run, a value from one of these years is randomly picked. Note that negative values are retained. They reflect that the survey may under-estimate maturing biomass in some years, and maturing biomass is therefore allowed to increase from October to January in these cases.

The Barents Sea capelin team suggested using survey mortality from age 2 to age 3 as basis for the autumn mortality for maturing capelin in the forecast. The mortality from age 2 to age 3 was considered to be more representative of mortality for maturing capelin than mortality from age 1 to age 2. This approach assumes that natural mortality from age 3 to 4 is the same as natural mortality from age 2 to 3. The panel discussed that survey mortality from age 2 to 3 likely reflects the mortality of maturing capelin better than survey mortality from age 1 to 2. It was further agreed that the survey years prior to 1987 (i.e. 3-year-old measured in 1988 compared to 2-year-olds measured in 1987 is the first pair included) should be removed from the estimation since they represent a period when the ecosystem was in a very different state than in more recent years. It was further agreed that estimates associated with the problematic survey year 2016 should be removed.

The panel recommended that the survey mortality used for the forecast in the annual assessment should be picked randomly from this list for each simulation run, and the list should be updated annually unless there are issues with the survey.

4.2 Predation model

Predation mortality of mature capelin from January 1st to April 1st is assumed to result from consumption by immature cod. The biomass consumption per unit time (i.e. the functional response) is a function of available mature capelin biomass and the predation ability of immature cod. This function has two parameters, C_{max} and $C_{1/2}$. Parameters of the functional response model are estimated using estimates of capelin biomass from the acoustic survey, and cod stomach contents, abundance and distribution data. These parameters are then bootstrapped by resampling pairs of parameters, assuming that consumption is normally distributed with expectation equal to the true consumption and with a constant variance.

During the benchmark meeting, there was a request made to check how the variance estimate is produced, and to check that the estimates are sensible. The original functional response used was a Holling Type II functional response (i.e. it does not allow for prey switching). Given the range of capelin biomass (low capelin biomass) used in the functional response, the function was always in the linear phase (i.e., it resembled a Type I functional response model). In some years with low estimates of capelin abundance, this model resulted in consumption estimates by cod higher than the actual estimates of capelin biomass. There was also a request to fit a Holling Type III functional response, which would allow cod to switch prey in years when capelin biomass is low. The Barents Sea capelin team fitted a Type III functional response (assuming an exponent of 2). This model was more parsimonious and alleviated to a certain extent the issue of consumption exceeding capelin biomass in years of low capelin biomass. Moreover, the estimates of capelin consumption by cod were very similar to those obtained from the Type II functional response in years of high capelin abundance. Given this exercise, and that biologically the Type III functional response makes more sense that the Type II, the panel recommended that a Type III functional response (with exponent 2) be adopted.

The Barents Sea capelin team also showed that it is important to account for the proportion of the immature cod outside the capelin area (i.e. the Svalbard cod) when estimating predation mortality. The panel recommended that this proportion should be estimated based on the annual surveys. There was agreement that corrections need to be made for years prior to 2014 when the survey was extended because this component was not captured by the survey before that year.

There was discussion around which version of the natural mortality (see previous section) should be used to estimate the consumption parameters. The current approach is to use averaged natural mortality. However, it is fairly easy to move to annual mortality rates. The panel proposed to use annual values, but to fall back to averaged (over the same period) if this proves to be unstable. No other predators are considered to exert sufficient mortality to affect the dynamics of the capelin stock. There were discussions about the spatiotemporal distribution of minke and humpback whales, but the panel agreed that they likely do not overlap with maturing capelin enough to be relevant sources of mortality.

There was also discussion on particular years where cod consumption is greater than available capelin resulting in negative spawning stock biomass. It was suggested to force a no negative biomass estimate when calculating the consumption parameter C_{max} and $C_{1/2}$. The Barents Sea capelin team explored this suggestion during the meeting and related that forcing no negative biomass estimates has an impact of fitting predation parameters that will lead to less consumption in all years and therefore underestimate predation mortality. The panel then recommended further research on what should be done in the estimation of the consumption parameters in the event that predation mortality could lead the stock to negative biomass.

5. Blim estimate

The current estimate of Blim is 200 kt. This is based on the 1989 biomass which represent the lowest SSB that produced good recruitment. The actual biomass estimated for this year is 96 kt, but this was increased to 200 kt to account for unaccounted uncertainty. The panel discussed criteria for setting Blim and if the uncertainty in Blim should also be accounted for. There was an approach suggested to use the upper confidence interval of the SSB on April 1st as the basis for setting Blim. However, the panel recommended not to account for uncertainty in the Blim, since uncertainty is already accounted for in the harvest control rule.

During the meeting it was discussed whether the recruitment of the 1989 year-class was an accurate basis to use for estimating Blim. It was agreed that 1989 was an outlier in the time series in terms of recruitment and that this good recruitment occurred in a year with unusually low abundance of herring ages 1 and 2. The first strong herring year-class after the collapse, the 1983 year-class, had left the Barents Sea in 1986 and no new strong year classes had followed it.

The SSB-recruitment relationship excluding the early years with low herring abundance show that recruitment collapse can happen at any level of SSB, but good recruitment starts to appear from an estimated SSB of a little less than 100 kt. The 1990 year class was the highest recruitment year resulting from a SSB of approximately 100 kt. Therefore, it was recommended by the panel to use 1990 as the basis for Blim. The benchmark notes that there are unquantifiable uncertainties around the estimate of Blim and the assumption of an unbiased survey.

6. HCR

The existing HCR for Barents Sea capelin contains a precautionary buffer that will be avoided in the HCR. This precautionary buffer lifts the Blim value from just under 100kt to 200kt. The inclusion of a precautionary buffer in Blim is not standard ICES procedure and should be revisited. A revised Blim directly based on lowest observed SSB which led to good recruitment with no precautionary buffer was proposed during the WKCAPLEIN 2022 workshop. However, the workshop was also tasked with evaluating the precautionary nature of the existing HCR with the buffer and there was no examination of an alternate formulation without the precautionary buffer. Therefore, the workshop recommends that the actual HCR be re-worded to require that the SSB after fishing should remain above Bescapement rather than above Blim, and that the Bescapement remain at the existing 200kt.

These recommended changes would ensure that the HCR is worded in terms of modern ICES procedures, while meeting the goal here of evaluating the existing HCR as remaining precautionary. It may be that a HCR with a lower Bescapement and potentially set at the actual Blim in the Barents Sea would also be precautionary, however this was not evaluated at this meeting and would require a specific HCR evaluation.

Iceland-East Greenland-Jan Mayen (IEGJM) capelin

1. Abundance estimates

The IEGJM capelin stock assessment is based on the absolute abundance estimated by acoustic measurements in autumn and/or winter (January/early February) since 1980. In many seasons, multiple acoustic surveys are conducted, always one in the autumn and in most years one or more in the winter. The mature biomass estimates in each survey are averaged along with uncertainties to give the biomass of mature capelin at January 15th . Then, the spawning stock biomass is estimated by projecting the stock from January 15th to March 15th with the application of predation mortality.

Scientific advice on the status of the stock is provided in three different instances:

- Initial advice: it is provided during the winter, one year in advance. This serves as an outlook for the next fishing season.
- Intermediate advice: it is provided after the fall survey, i.e one month in advance of the earliest start of the fishing season. Usually the fisheries start later but the intermediate advice helps industry to plan logistics for the upcoming fishing season.
- Final advice: it is provided after the spring (winter) survey. This is the final quota advice and replaces the intermediate advice.

The management of the IEGJM capelin stock has to explicitly include the objectives of preserving the spawning stock and minimizing the effect of removals on the ecosystem.

1.1 Fall Survey

The survey conducted in the autumn targets the mature and immature component of the stock. It procures an initial idea of what could be the magnitude of the spawning stock biomass for the following winter and is used to set an intermediate advice before the beginning of the fishing season. This survey was traditionally carried out in waters off the North of Iceland. However, capelin distribution shifted dramatically around 2000 and after 2009 the survey was expanded to cover a large area along the east coast of Greenland (roughly between the parallels 64° and 74° N).

In most of the years where fall and winter surveys were conducted there was a good level of consistency between both spawning biomass estimates i.e. the estimated SSB during the autumn is relatively equal or lower than the surveyed SSB during the winter. In other words, the SSB estimated in the autumn should never give an intermediate advice that is greater than the final advice based on the final SSB estimated in the winter. The intermediate assessment conducted in October is based on prediction that the biomass of mature capelin on the 15th of January next year will be the same as in the autumn survey. In the 2021/2022 season the autumn survey indicated much higher mature biomass than the winter surveys, something not observed before in the data series. This led the IEGJM capelin team to propose different suggestions to deal with this issue that were discussed at the benchmark meeting:

- The autumn survey biomass used in the assessment should be compiled by reducing number at age by M=0.035/month, multiplying by mean weight at age of the same year class in winter;

- The autumn survey should have a maximum weight of 1/3 in the final assessment. No such limit was in the assessment adopted by WKICE 2015;
- Age distribution in the autumn and winter surveys should be compared and the autumn survey corrected for any discrepancy if required;
- Acoustic surveys in the warm sea (region to the south east of Iceland) should not be included in the assessment (see WD I01);
- Acoustic surveys late in the season north and north-west of Iceland should not be included or added to previous surveys except if a large part of the total stock is found there.

Of those suggestions, the panel recommended only that the autumn survey should have a maximum weight of 1/3 in the final assessment. This recommendation was made because of the greater uncertainty associated with the autumn survey resulting from the larger area to cover and more patchiness in the distribution of capelin schools. It was also agreed by the panel that giving this uncertainty, the simple rule of 1/3 weighting of the autumn acoustic survey should resolve the potential risk of setting a higher intermediate advice than the final advice.

1.2 Winter survey

The winter surveys take place from mid-January to early February and targets the mature component of the stock during the spawning migration. This survey occurs in waters off the North and East of Iceland. It has to be conducted after the mature stock enters the Icelandic continental shelf north of Iceland and before they migrate into the warm sea south-east of Iceland when they take the usual eastern route clockwise around Iceland to the spawning areas in the south and west. The timing of the migrations varies, and in some years the first schools have migrated into the warm sea (where acoustic measurements are unreliable) before the last schools enter the continental shelf. In some years, more than one survey is conducted and the average spawning stock biomass is used to formulate the final advice for that fishing season.

During the benchmark meeting, it was mentioned that in some years with a number of surveys some of the surveys were invalid because of factors like storms, sea ice and coverage issues. The sea ice problem is most common in autumn surveys but storms cause more problem in winter when the capelin is actively migrating. Therefore, the panel recommended to use expert judgement on which surveys to combine to get the spawning stock biomass estimates.

1.3 Combining survey estimates

The mature biomass estimates in each acoustic survey (i.e. 1 fall survey, and 1 or more winter surveys) are averaged along with uncertainties to give the biomass of mature capelin at January 15th. The current approach used to average the surveys is to combine all data in one overall Monte Carlo simulation. This implicitly assumes that the two (or more) surveys are actually one survey. Abundance estimates (and corresponding variability estimates) are obtained from this combined Monte Carlo. During the benchmark meeting, this approach was deemed problematic given that the autumn and winter surveys cannot be considered a unique survey as they describe different components of the stock, in particular the winter survey targets the mature component of the stock. In addition, the spatial variability of the area covered during the autumn and the winter survey are vastly different.

One recommendation made by the panel during the benchmark was to carry out separate Monte Carlo simulations for autumn and winter, while the winter Monte Carlo simulation may combine multiple surveys. Abundance estimates from the separate Monte Carlo simulations should then be combined using appropriate weighting of the surveys giving the greater uncertainty of the autumn survey and the greater accuracy of the winter survey. The current approach is to give identical weights to all surveys. There was no agreement as to what these weightings should be, but there was a general consensus that the winter surveys should receive more weight than the autumn surveys. A recommendation made by the panel for future research was to use an approach such as inverse variance weighting.

It was also recommended by the panel that how the survey CVs are combined should be re-evaluated. There was a research recommendation to pay particular attention to this task in the future, as the current approach does not seem to be correct; it is currently estimated as $\sigma_{u3} = 0.5\, x\, \sqrt{\sigma_{u1}^2 + \sigma_{u2}^2}$. This approximation may work when the estimates are similar, but it is problematic when the estimates differ as was the case in recent years.

Given that time precluded the researchers from carrying out these alternative proposals during the timeframe of the benchmark, the panel recommended that the current approach be used, but with a strong recommendation that a dedicated correspondence review looking at these issues should be carried out in the near future.

1.4 Target Strength – fish length relationship

A study carried out by the IEGJM capelin team on the influence of fish behaviour and physiology on target strength values was presented at the benchmark and addressed the following research questions:

- Are narrowband (CW) mean TS-length assumptions used currently in the stock assessment correct?
- Is there a significant variability in capelin backscatter that should be accounted for instead of using overall geometric mean?
- Can broadband (FM) measurements increase the quality of acoustic estimates?
- Can the high-density FM single target detections give full count of targets in the sampling volume?

Results of this study suggests that TS varies with depth, and potentially with season, vessel speed, fish length, condition, and swim bladder size. These results have implications for the assumption of q=1. Importantly, these results suggest that the catchability coefficient of the acoustic survey is lower than 1, and these data do not indicate that catchability is over 1. This suggests that the assumed absolute abundance calculated from the acoustic surveys can be considered underestimates.

The panel recognized the importance of this work and recommended that research on this matter continues. However, given that the impact of this work means that the advice provided is precautionary, the panel recommended to continue setting the quota advice based on the assumption of q=1.

1.5 Coefficient of variation of surveys

The acoustic autumn surveys have in general a high CV because of the patchy distribution of the stock. Similarly, during the winter survey, the tight schools of high concentrations can be unevenly distributed in the survey area. By doing a finer-scale survey in areas of high concentrations one can introduce the problem of underestimating the total biomass in the survey region. Therefore, identifying a bound on the CV or taking an average may be a better approach to control the uncertainty in the survey estimate instead of estimating by survey which could be tracking the noise in the data.

One element that was discussed during the benchmark meeting was the methodology to estimate the survey CV which is done by bootstrapping the abundance estimates in predefined squares following the survey design. The panel requested to verify if there was a better way to estimate the CV, for example bootstrapping on transects instead of squares, because in some cases where capelin schools are aggregated and not patchy in the square, it can result in a high CV. Because of the short time frame of the meeting, it was not possible for the IEGJM capelin team to verify if other methods would be more appropriate. Therefore, the panel recommended to keep using the overall bootstrap on squares and to investigate more accurate methods to estimate the survey CV as future research.

Another request that was made by the panel during the meeting was to compile the CVs of all autumn and winter surveys as far back in time as possible. The objective was to visualize the fluctuations in CV of the autumn and winter surveys over time, and between the autumn survey, individual winter surveys, and the CV of the combined final advice. There are also instances where more than one advice is issued per fishing season, and it was of interest to examine how the CV differs among these. There are also instances when autumn and winter surveys are combined to generate the advice and the implication of the estimated final CV needs to be assessed. The overarching goal of this exercise was to determine whether an average CV could be used over the years instead of estimating CV every year given the high variability in estimated CVs. The CVs were compiled from 2013 to 2022. There are considerable fluctuations for the winter surveys whereas the autumn CV fluctuates between 0.2 – 0.3. The reasoning for the differences between the individual winter surveys is that some of the surveys are partial coverages conducted in appropriate weather windows.

Following those analysis, the panel recommended to use the average CV values of the winter and autumn surveys from 2013 to 2022 for the final advice. Following the meeting, the IEGJM capelin team expressed their disagreement with this recommendation, given that a thorough assessment of the implications of adopting a fixed average CV could not be completed. A follow-up meeting was held on March 3, 2023 to address this issue. The IEGJM capelin team recommended to keep the current procedure, i.e. use annual CV for fall and winter surveys. The panel agreed with this recommendation. The panel also made a strong recommendation to hold a dedicated correspondence review in the near future to revisit this issue.

2. Maturation

Assignment of maturity stage is based on visual inspection of whole gonads. This method is considered fast and unexpensive. A study was presented during the meeting and aimed at comparing the maturity stage assignment based on visual inspection and on histological examination of structures within oocytes and testes. The latter method is more expensive and more time consuming, but generally provides more accurate determinations.

The results suggest that the error rate does not differ between the micro and macroscopic methods. The error rate seems to be higher in winter than in the fall. The hardest length group to assign maturity stage is the 14-15 cm length group. The length at which 50% of the individuals are mature (L50) increased approximately 1cm in the last 22 years whereas condition factor of both males and females has improved since 2009.

The panel agreed that macroscopic assignment of maturity works well, with the caveat that if the abundance estimate produced in the fall is large (this has happened only once in 2021), there may be an overestimation of the proportion of fish that will mature and therefore there may be a need to place a limit on the TAC provided in the fall. In 2021, when there was a very large year class, large capelin had very small gonads and were unlikely to mature in winter 2022 which can be related to density-dependent effects on maturation.

3. Projection to assessment date

The mature component of the stock is predicted ahead from January 15th to March 15th. This projection is carried out considering fisheries catches (most catches occur in February in the area south of Iceland) and predation mortality by three important predators: cod, saithe and haddock.

3.1 Predation model

The predation model assumes that the mature component of the stock takes the traditional migration route clockwise around Iceland. In most years, the majority of the stock migrated following that route and nearly all the catches were taken from that component. The model assumes that the whole maturing stock is east of Iceland on January 15th, and that spawning occurs in the south and southwest, with a higher proportion spawning in the southwest. The area is separated in three spatial components, and different proportions of the stock are assumed to progress in the spawning migration in 2-week time blocks. During these 2-week periods, the capelin is exposed to varying abundances of predators. The most important series of predators' stomach data is from the demersal survey, usually collected from the 1st to the 20th of March, near and in the capelin spawning period. Since there is a temporal mismatch between the collection of predator stomach data and the collection of capelin acoustic data, the model uses biomass of predators from assessments in year y to estimate consumption in year y+1. The functional responses of the three predators are assumed to be Holling Type II functional responses. There is limited knowledge on both parameters of the functional response. The parameters of the functional response cannot be estimated, given the temporal mismatch mentioned above. The consumption of each predator in each area entails the use of different C_{max} and $C_{1/2}$ parameters by predator and area.

There were discussions about how the estimates for the parameters and their corresponding variabilities are obtained, particularly the value of the half feeding parameter ($C_{1/2}$). It is understandable that the C_{max} parameter can be obtained from gastric evacuation models, but it is not clear how the estimate of $C_{1/2}$ is obtained. Functional responses were bootstrapped assuming the parameters follow a uniform distribution and are uncorrelated. This last assumption is not realistic and may impact the resulting estimates of capelin consumption by their predators. Therefore, the panel made a request to assume that the parameters follow a normal distribution which may alleviate the issue of the parameters being uncorrelated. The IEGJM capelin team redid the bootstrap assuming normal distribution and found minimal differences with the results that assumed uniform distribution.

The panel recommended to approve the above approach, provisional on the test of drawing parameters from a different distribution. This exercise was carried out and differences were minimal. Therefore, the panel approves the approach. The panel notes that when drawing C_{max} and $C_{1/2}$ parameters in the bootstrap, these linked parameter pairs are correlated.

3. Blim estimate

The reference point used to set the final advice for the IEGJM capelin is Blim which represents the lowest SSB value that can produce a good recruitment year. During WKICE 2015, the Blim value was set at 150 kt based on the average of the 3 lowest values of SSB (1981, 1982, and 1990) that led to average recruitment.

Prior to WKCAPELIN 2022, the spawning stock since 1981 was recalculated using the prediction model adopted in 2015 , i.e. taking into account uncertainty in the acoustic measurements and using the predation model adopted in 2015. This resulted in a downward revision of the SSB estimates.

During the benchmark meeting, stock-recruitment relationships were presented with a fitted hockey stick function. There is a break in the function around the values of SSB corresponding to the three years that were previously used to estimate Blim. Thus, the panel agreed to keep using the SSB in 1981, 1982 and 1990 as the basis for Blim. The new average value for those three years is 114 kt (i.e. a change from 150 kt to ca. 110 kt). Given the downward revision of the estimates of SSB, the new proposed Blim is a rescaling of the previously adopted limit reference point rather than a new proposal and therefore the panel recommended its adoption.

4. HCR

- The actual management plan is based on the criteria that there must be less than a 5% chance that the SSB after the fishing season is lower than Blim. A SSB estimate corresponding to January 15^{th} is projected forward to March 15^{th} using the predation model. The management framework currently relies on three advices made at different times of the year: The preliminary TAC serves as an outlook for the next fishing season. The method to set this preliminary TAC was not discussed during WKCAPELIN 2022.
- The intermediate TAC is set based on the amount of maturing capelin in the autumn survey.
- The final TAC is set based on the spawning stock biomass projected to March 15^{th}.

During the meeting there was some discussions regarding the intermediate TAC based on the maturing component of the stock in the autumn survey such as:

- Method to reduce the autumn survey initial quota to avoid having to reduce the quota in the winter.
- How to deal with conflicting autumn and winter surveys when the SSB estimates is the average of all surveys.

One recommendation made by the panel and adopted by the IEGJM capelin team was to limit the intermediate advice to 2/3 of the SSB estimated in the autumn survey. A formal process to set the intermediate advice should also be evaluated as future research. Another recommendation made by the panel was that in years where the average SSB in the autumn and winter surveys is being used in the final winter advice, the weight of the winter survey should be double of the autumn survey. However, this recommendation was not in the meeting report of the IEGJM capelin team and should be incorporated in the management plan until the review of combining surveys can be conducted.

Conclusion

The success of the escapement HCR applied for both the Barents Sea and the IEGJM capelins rest on the stock estimate being unbiased, the uncertainty of that estimate being correctly characterised, and the estimated Blim being accurate. None of these three things can be guaranteed and a more detailed investigation would be needed to conduct a full management strategy evaluation. However, the work at this benchmark has followed standard ICES practices. The inclusion of predation mortality in an attempt to avoid biases from that source ensures that the stock dynamic is more detailed and realistic than for many other fish stocks. The uncertainty associated with annual values of the different indices used for the projection of SSB at the time of spawning are the best available. Blim has been derived following ICES procedures, although no estimate of uncertainty has been placed on it. The workshop therefore evaluates that the meeting has conducted best available science following ICES procedures. The two HCRs are therefore considered precautionary in regards to ICES escapement strategy. Furthermore, the HCRs implemented for managing the Barents Sea and the IEGJM capelin stocks seem to have worked well since 1991 and 2015, respectively. Provided no significant change is made to the HCR, the amendment to the Barents Sea HCR wording to fit with modern ICES terminology (see section 6 of Barents Sea capelin), or to the performance of the underlying models, the rule should continue to be as precautionary as previously. WKCAPELIN therefore concludes that both HCRs remain precautionary and that ICES can continue to give advice on this basis.

As external experts invited to participate in the WKCAPELIN 2022 benchmark of the Barents Sea and Iceland-East Greenland-Jan Mayen capelin stocks, we approve the methods used for the assessment of both stocks and the recommendation made during the meeting by the panel.

Annex 6: Stock annex edits

ICES. 2023. Stock annex: Capelin (*Mallotus villosus*) in subareas 1 and 2 (Northeast Arctic), excluding Division 2.a west of 5°W (Barents Sea capelin). ICES Stock Annexes. Report. https://doi.org/10.17895/ices.pub.23600088

ICES. 2023. Stock annex: Capelin (*Mallotus villosus*) in subareas 5 and 14 and Division 2.a west of 5°W (Iceland and Faroes grounds, East Greenland, Jan Mayen area). ICES Stock Annexes. Report. https://doi.org/10.17895/ices.pub.23600094