HISTORICAL BARENTS SEA CAPELIN QUOTA ADVICES COMPARED USING ORIGINAL AND UPDATED (2023) FORECAST MODEL CONFIGURATIONS

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RAPPORT FRA
HAVFORSKNINGEN
NR. 2025-5

Title (English and Norwegian):

Historical Barents Sea capelin quota advices compared using original and updated (2023) forecast model configurations

Samanlikning av historiske kvoteråd for lodde i Barentshavet basert på original og oppdatert konfigurasjon av framskrivingsmodell

Report series:	Year - No.:	Date:
Rapport fra havforskningen	2025-5	28.01.2025

ISSN:1893-4536

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Distribution:

Open

Project No.:

15568

Program:

Barentshavet og Polhavet

Research group(s):

Pelagisk fisk

Number of pages:

19

Summary (English):

The quota advice for the Barents Sea capelin stock happens in two steps: first the stock size is estimated based on a Russian-Norwegian survey in September. After that, the estimated amount of maturing capelin is used as basis for a prognosis for the spawning stock 6 months ahead in time. As part of the 2022 capelin benchmark, the configuration of the model used for the prognosis, Bifrost, was updated. In the present document, we make a comparison of quota advice for the advice years 2005-2023 based on forecasts with the updated and original model configurations. The results show that the catch advice in general would have been higher with the updated configuration, but the years with a no-fishery-advice were the same with the updated and original configuration. The comparison further showed that the changes in parameter settings of the cod consumption module in addition to the parameters set for natural capelin mortality in the autumn (1 October to 1 January) had the greatest impact on the advice. It must be noted that the model configuration is partly adapted to the current ecosystem state, so the comparison is most relevant for the most recent years. Furthermore, some parameters including the natural capelin mortality in the autumn and the proportion of immature cod in the Svalbard area will be updated each year as part of the capelin assessment, so the results of a direct comparison with historical advice is expected to change each year.

Summary (Norwegian):

Bestandsrådgjevinga for barentshavslodde skjer i to steg: først blir bestanden estimert basert på eit norsk-russisk akustisk tokt i september. Deretter blir den estimerte mengda av modnande lodde brukt som basis for ein prognose for gytebestanden 6 månader fram i tid. Modellen brukt til prognosen, Bifrost, blei oppdatert som ein del av metoderevisjonen på barentshavslodde i 2022. I denne rapporten samanliknar me kvoteråda for åra 2005-2023 basert den oppdaterte modellkonfigurasjonen med kvoteråda basert på den originale konfigurasjonen. Resultata viser at rådet ville vore høgare med den oppdaterte konfigurasjonen, men at åra med råd om nullfiske er uforandra med oppdatert konfigurasjon. Samanlikninga viste også at det var modellendringar relatert til torskekonsum som hadde størst innverknad etterfølgt av endringar for naturleg dødelegheit om hausten. Modellkonfigurasjonen som blir brukt er delvis tilpassa tilstanden i økosystemet som endrar seg over tid, slik at samanlikninga er mest relevant for perioden som ligg nærast i tid.

Content

1 - Background

The Barents Sea capelin stock assessment and quota advice are made in two steps. In the first step abundance, biomass and demography of capelin is estimated based on the annual Russian-Norwegian Barents Sea Ecosystem Survey (Eriksen et al. 2018). In the second step, the estimated biomass of maturing capelin from this survey is used in a 6-month forecast to estimate the spawning biomass which is the key input for the harvest control rule. The forecast is done using the model Bifrost (GitHub - IMRpelagic/bifrost: Capelin stock assessment package).

The settings of the forecast model were evaluated during the 2022 capelin benchmark (WKCAPELIN; ICES, 2023a), and some assumptions and parameter settings were changed; The estimated cod consumption of capelin from 1 January to 1 April was changed to more realistically reflect the assumed natural cod consumption (Annex 3, WD_BS7 in ICES, 2023a). The estimated mortality of capelin in the autumn was also updated to include a wider range of possible mortality values (Annex 3, WD_BS6 in ICES, 2023a). There were also made changes to which cod are spatially excluded from feeding on maturing capelin based on updated survey estimates. Cod growth and mortality was also assumed to cancel out in the updated model configuration reflecting updated knowledge of the cod stock. Finally, a simplification was made to how the maturing proportion of the capelin stock is defined.

These changes were implemented during the 2023 capelin assessment and applied to provide the catch advice for 2024. As part of the evaluation of harvest control rules for capelin, there was a request from the managers to revise how the quota advice would have been for the advice years 1990-2023 with the updated model configuration. In this document, we compare the quota advice derived from using the updated and the original model configuration and evaluate the impact of each configuration change on the final quota advice.

1.2 - **Approach**

1.2.1 - *Basis for comparison*

The capelin assessment and advice are based on a two-step procedure which includes first an estimation of the maturing capelin stock on 1 October and second a forecast of the maturing stock until the assumed end of spawning on 1 April. Here, we focus on the second step which is the forecast.

The stochastic forecast of maturing capelin includes natural mortality from 1 October to 1 January, and next capelin mortality from 1 January to 1 April which is explicitly modeled as consumption by immature cod, plus catch (see section below and the stock annex *ICES, 2023b* for further details).

1.2.2 - *Years included in the comparison*

It was requested to focus the comparison on the years 1990 and onwards. However, we could not fully meet this request for reasons presented in the following.

A Barents Sea capelin quota advice on the form *5% probability of SSB < 200 000 t* was first given for the advice year 2000 (Gjøsæter et al. 2002). Prior to that, the advice was associated with a different harvest control rule and stochasticity was not added. We therefore believe a comparison of advice years prior to 2000 has limited value in this context, and these early years are not included. We also exclude the years 2000-2004 since the ecosystem survey time series providing the data for the current forecast began in 2004, and a full validation of the forecast from *Bifrost* in R (see section below) has been done only for this time series. Lastly, we exclude the advice for the years 2015 and 2023 since *ad hoc* adjustments to the advice were made for these years due to incomplete survey coverage.

Despite the exclusion of years, we have a range of years for comparison including several years with zero-catch advice and several years with relatively high catch advices.

1.2.3 - *Basis for historical forecasts*

From 2002 to 2022, the capelin forecasts in the operational assessments were conducted using *CapTool*, an @Risk add-on to MS Excel customized for capelin stock assessment. Some forecast parameters were set in *CapTool* while others were estimated using the model framework *Bifrost* developed in Mathematica. More detail about the historical assessment can be found in Gjøsæter et al. (2002, 2015).

In 2021, the *Bifrost* framework together with the *CapTool* forecast tool were converted into the R programming language (GitHub - IMRpelagic/bifrost: Capelin stock assessment package), and comparisons with historical *CapTool* forecasts showed very high consistency. In the 2023 capelin assessment, the *Bifrost* R package was used for the forecast with parameter settings updated according to what was agreed during the capelin benchmark WKCAPELIN (ICES, 2023a) and subsequent discussions between PINRO and IMR.

For the present comparison, we have reorganized the *Bifrost* R package to streamline data flow, enable faster computation, and improve reproducibility and transparency.

1.2.4 - *Assumptions and parameter settings*

Table 1 provides an overview of the configurations that changed from the original to the updated model. Below, we describe these configurations in some more detail.

Maturation. Prior to the forecast, the capelin stock as estimated from the survey data must be divided into an immature and a maturing component of which only the maturing component is used in the forecast. The division is done according to capelin length and follows:

$m_l = 1/(1 + \exp(4p_1(p_2 - l)))$

where m_l is the proportion of maturing fish at length l in cm. p_2 is the length at 50% maturation and p_1 (maturation intensity) is the slope.

In the original configuration, a p_1 of 3.5 was assumed and a p_2 of 13.89±SD 0.075 (See table 1 below and WD_BS9 in Appendix 3 of the WKCAPELIN report; ICES, 2023a). The updated configuration uses the parameterization p_1=50 and p_2=14. Since the length resolution in the data is 0.5 cm, the effect of this parameterization is in practice a cut-off between immatures and maturing capelin at 14.0 cm.

Mortality in the autumn. The parameterization of mortality of capelin from 1 October to 1 January is based on survey data (See Tjelmeland and Bogstad, 1993 and WD_BS6 in Appendix 3 of the WKCAPELIN report; ICES, 2023a). In the updated configuration, the procedure is to compare the abundance of immature capelin at age 2 in a survey year (Y) with the total abundance of capelin at age 3 in the following survey year (Y+1). Assuming that the annual natural mortality is the source of the difference between these two estimates, the autumn mortality (i.e. the monthly mortality) can be derived from this. For each simulation run in the forecast, a value for the mortality in autumn is drawn from a distribution of monthly mortalities derived from the years 1987 and until present, except years associated with incomplete survey coverage.

Also in the original configuration, autumn mortality was based on survey data, but mortality from age 3 to age 4 was included in addition to mortality from age 2 to age 3, and parameter values per year were the output of a likelihood function including the maturity parameters p_1 and p_2 resulting in 1000 replicate values per year which were drawn from in each simulation run of the *CapTool* forecasts. Using mortalities from age 3 to age 4 was relevant in the 1970s and early 1980s, but thereafter the age 4 abundance has in most years been extremely low and thus using age 3 to age 4 mortality was no longer relevant. Importantly, the mortality values for some years (seems to be the ones with highest and lowest values) were excluded from the forecast based on an expert evaluation in the period 2011-2022. In the updated configuration all years are included except those years associated with poor survey quality, and this was the case also prior to 2011.

Functional response parameters (C_{max} and C_{half}) for cod consumption rate of capelin. In the original configuration, the cod consumption rate of capelin followed a functional response of type II. However, the parameters used for C_{max} and C_{half} resulted in a type I response within the range of abundances of cod and capelin observed in nature. This was probably not intentional since it is not reflected in the old stock annex (ICES, 2009). Following from WKCAPELIN, parameters C_{max} and C_{half} for a Type III functional response curve were re-estimated which is described in WD_BS7 in Appendix 3 of the WKCAPELIN report, ICES, 2023a.

Proportion of immature cod in Svalbard area. Immature cod in the Svalbard area are assumed not to feed on maturing capelin due to lack of overlap in distribution. In the original configuration, the proportion of immature cod in the Svalbard area was estimated based on data from several surveys covering a period from 1983-2004. Following from WKCAPELIN, the updated configuration uses the estimated proportion of immature cod by age in strata 24-26 (Svalbard area) in the Barents Sea winter survey from 2014 until the assessment year (see Fall et al. 2024 for map of stratas). For both the original and the updated configurations, the values used in each simulation run are drawn randomly from the years available.

Mortality of immature cod. In the original configuration a cod mortality of Z/12 per month was assumed from 1 January to 1 April, where the Z equaled the cod mortality used in the annual cod assessment for generating the cod prognosis. The updated configuration follows from WKCAPELIN and it is now assumed that immature cod biomass is constant from 1 January to 1 April on the rationale that in biomass terms, decreased abundance at

age due to mortality cancels out increased weight at age due to growth (See section 2.1.8 in WKCAPELIN report, ICES, 2023a).

Data and parameters that were not changed for the comparison included:

CV by age for capelin abundance. This was fixed at 0.2 with the original configuration and we keep it at 0.2 for the updated configuration. The recommendation from the WKCAPELIN benchmark was that an average CV by age from the last 5 survey years be used, but the 2023 assessment revealed that this was inappropriate in cases where the most recent estimate of abundance at age for some age groups is much higher than the previous 4 survey years.

CV by age for cod abundance. This is kept at 0.3 and is based on the cod assessment.

Suitability of capelin for cod. This parameter used in the cod consumption module provides the assumed proportion of each cod age group that consumes capelin.

Cod abundance, individual weight and maturation. The cod abundance, individual weight and maturation used in the forecast are from the cod assessment prognosis. We use these prognoses also for the comparison here. It is possible to parameterize with cod abundance from the updated cod assessment similar to what was done in Gjøsæter et al. (2015), but that is outside the scope of the present comparison.

Capelin abundance and individual weight. We use the capelin abundance estimates that were used for the original advice. These estimates have been updated for the years 2004-2015 (WKCAPELIN Appendix 3 WD_BS1; ICES, 2023a), but we consider it most relevant for this comparison to use original estimates.

Table 1. Model assumptions and input parameters used in the original forecast model versus the updated.

Parameter	Original	Updated	Comment
Maturation; maturation intensity, p_1, and length at 50% maturation, p_2.	p_1=3.5, p_2=13.89 ±SD 0.075	p_1=50, p_2=14	Changed after WKCAPELIN. Parameters documented in WKCAPELIN report Appendix 3 WD_BS9; ICES, 2023a.
Mortality autumn	*2004-2006)* Survey mortality distribution based on years 1972-2002. *2007-2010)* Survey mortality distribution based on years 1972-2006. *2011-2022)* Survey mortality distribution based on selected years (1980-85, 1990-93, 1997-2002).	Survey mortality distribution based on all years back to 1987 except those associated with the 2016 survey.	Changed following from WKCAPELIN 2023, see details in WKCAPELIN report Appendix 3 WD_BS6; ICES, 2023a.
Functional response parameters (C_{max} and C_{half}) for cod consumption	Parameters C_{max} and C_{half} for functional response curve of type II. Replicates from Bifrost used in CapTool.	Parameters C_{max} and C_{half} for functional response curve of type III. Replicates from Aldrin et al. (see WD_BS7 in Annex 3 in WKCAPELIN-report, ICES 2023a)	
Proportion immature cod in Svalbard area	Proportion immature cod in Svalbard area calculated based on a combination of several surveys. The proportion is drawn randomly from a time series of proportions from 1983-2004.	The proportion of immature cod in strata 24-26 (Svalbard area) from the Barents Sea winter survey. Proportions are drawn randomly from winter survey data covering the years 2014-assessment year.	The Svalbard area was not covered in the winter survey prior to 2014.

Mortality of immature cod	Z/12 per month during 1 January to 1 April. The Z is applying the cod mortality used in the assessment for generating cod prognosis	Zero - decreased biomass due to mortality is assumed to be cancelled out by increased biomass due to growth.	

1.3 - **Results**

Figure 1 shows the original quota advice compared to the quota advice using the 2022 configuration and 2023 configuration, respectively. The advices are also summarized in table 2. The 2022 model configuration corresponds to what was used historically except that parameterization of autumn mortality was different for the advice years 2008 to 2011 (see table 1). If the same natural mortality were assumed, the catch advice would have been close to 50% lower.

For the 2023 model configuration the catch advice would have been higher, ranging from a 16.3 to a 128.4 % increase. The forecast trajectories for all years investigated are shown in Figure A2. It should be noted that the years with advised catch >0 is the same for all configurations.

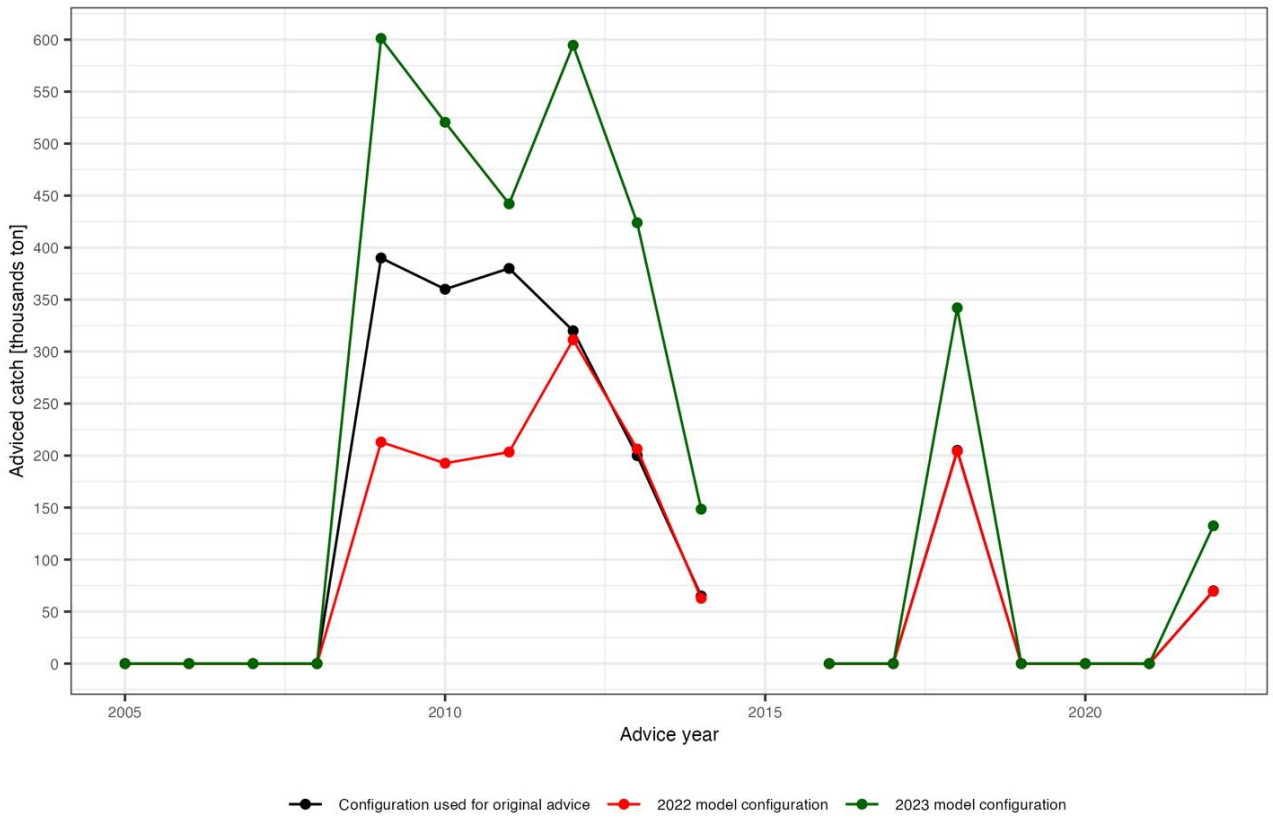

Figure 1. Catch advice following from different model configurations. The black lines and dots mark the original catch advice given for a particular advice year (note that the advice for a given year Y in the figure is given in year Y-1). The red lines and dots denote advice using the 2022 model configuration. The green lines and dots denote quota advice using the 2023 model configuration.

Table 2. Summary of the estimates and difference between estimates of original TAC advice for each advice year, with the recalculation using the 2022 and 2023 model configurations. The relative difference between the recalculation and the original TAC advice is also shown. Also, note that the TAC was set equal to the advice for all years where the advised TAC is shown in the table.

Advise year	Original advised TAC	Advised TAC using 2022 configuration	Relative difference (%) between original and 2022 configuration	Advised TAC using 2023 configuration	Relative difference (%) between original and 2023 configuration
2005	0	0	-	0	-
2006	0	0	-	0	-
2007	0	0	-	0	-
2008	0	0	-	0	-
2009	390	213	-45.4	601	54.1
2010	360	193	-46.5	521	44.6
2011	380	203	-46.5	442	16.3
2012	320	311	-2.7	595	85.8
2013	200	206	3.2	424	112
2014	65	63	-3.4	148	128.4
2015	-	-	-	-	-
2016	0	0	-	0	-
2017	0	0	-	0	-
2018	205	204	-0.4	342	66.9
2019	0	0	-	0	-
2020	0	0	-	0	-
2021	0	0	-	0	-
2022	70	70	0	132	89.2
2023	-	-	-	-	-

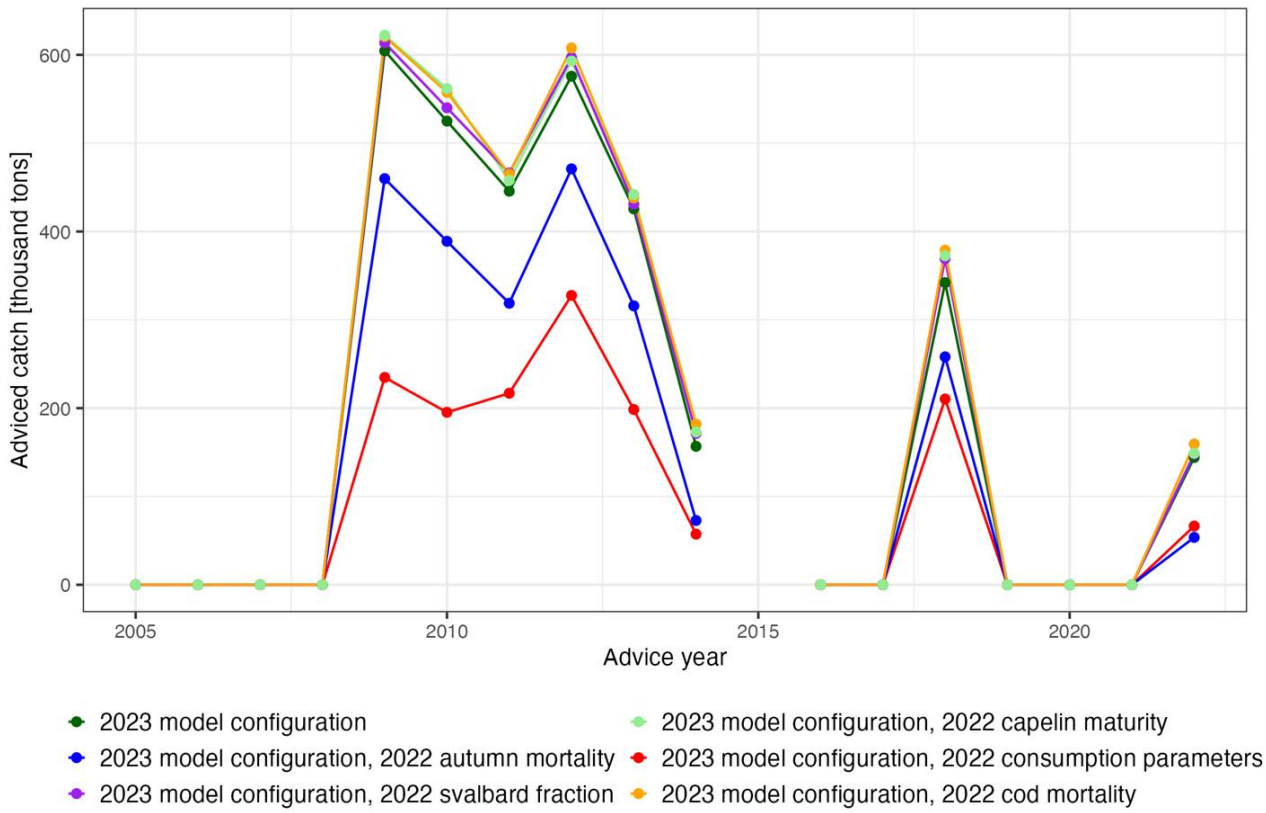

Figure 2. Catch advice following from change in single settings of the 2023 model configuration. The base run is the 2023 model configuration (dark green). For the other cases, the 2022 configuration of one configuration is used to evaluate the effect this has on the assessment.

Figure 2 shows the advised catch using the 2023 model configuration but with one parameter at the time set according to the 2022 configuration. The results show that the updated parameterization of the functional response curve for the cod consumption (C_{max} and C_{half}) has a great impact on the advice and generally leads to increased advice. The updated autumn mortality also has big impact and generally leads to increased advice. The other parameters matter less; updated maturity leads to a slight decrease in the advice since no capelin <14.0 cm are now included in the forecast whereas a small proportion of 13.5 cm capelin was included with the original setting. Updated cod mortality also leads to slightly lower advice likely resulting from a marginally higher modelled predation pressure. Similarly, the updated Svalbard component leads to a slightly reduced advice since a generally lower proportion of the immature cod is assumed to be in the Svalbard area (hence assuming no overlap with maturing capelin) than what was assumed before implying a slight increase in predation pressure (See figure A1 in Appendix).

1.4 - **Conclusions and future work**

-This comparison of original and updated model configuration for the capelin forecast shows that the advice is strongly influenced by the model settings, but that advises of zero-catch remain the same independent of model configuration.

-Overall, catch advice for non-zero advice years increased with the updated model configuration.

-The changes in settings with the most important impact on the advice were parameters for the cod consumption rate, and parameters for capelin mortality from 1 October to 1 January.

-It must be noted that the comparison was limited to settings explored at the WKCAPELIN benchmark, and that other settings might be relevant to explore further, for instance alternative maturation functions (See Jokar et al. 2021).

-Uncertainty in the forecast is being introduced by extracting cod stock size from the cod assessment prognosis (Gjøsæter et al. 2015). The prognosis might diverge significantly from later cod assessments when more knowledge about the stock has been acquired and the effect of this must be explored in future work.

1.5 - **References**

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1.6 - Appendix

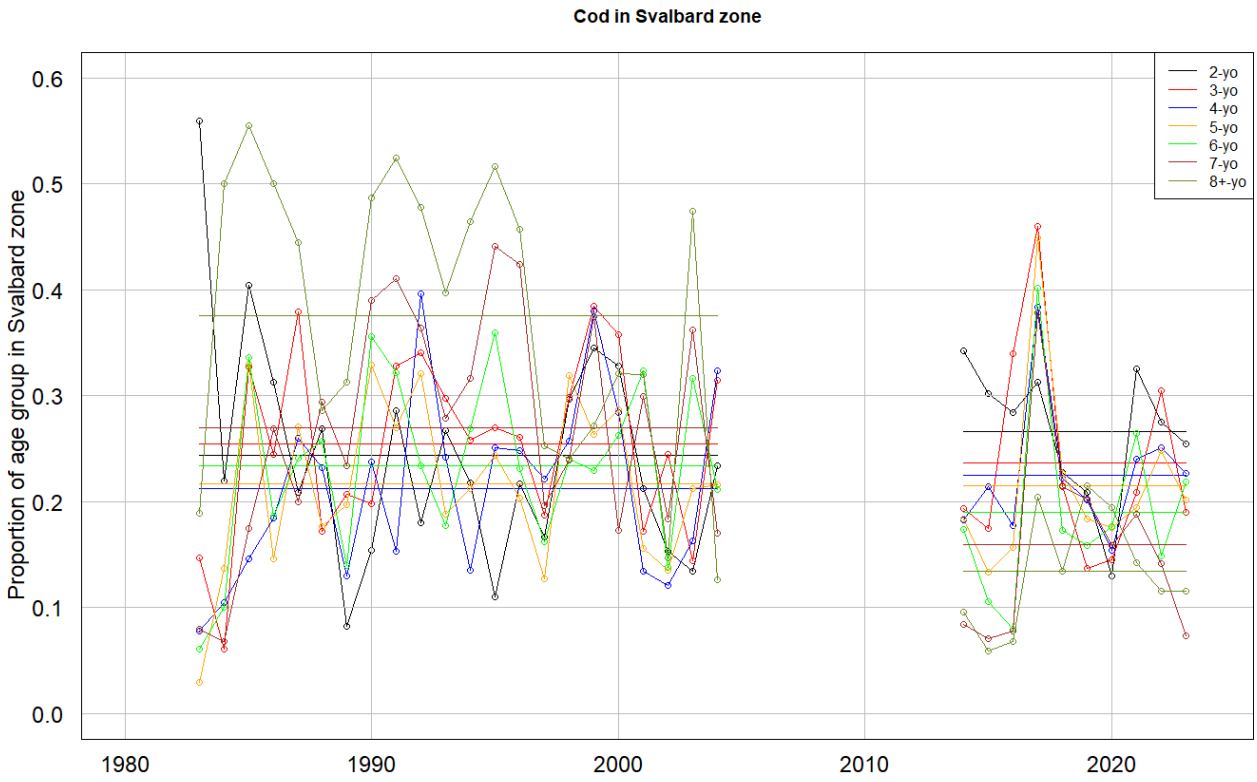
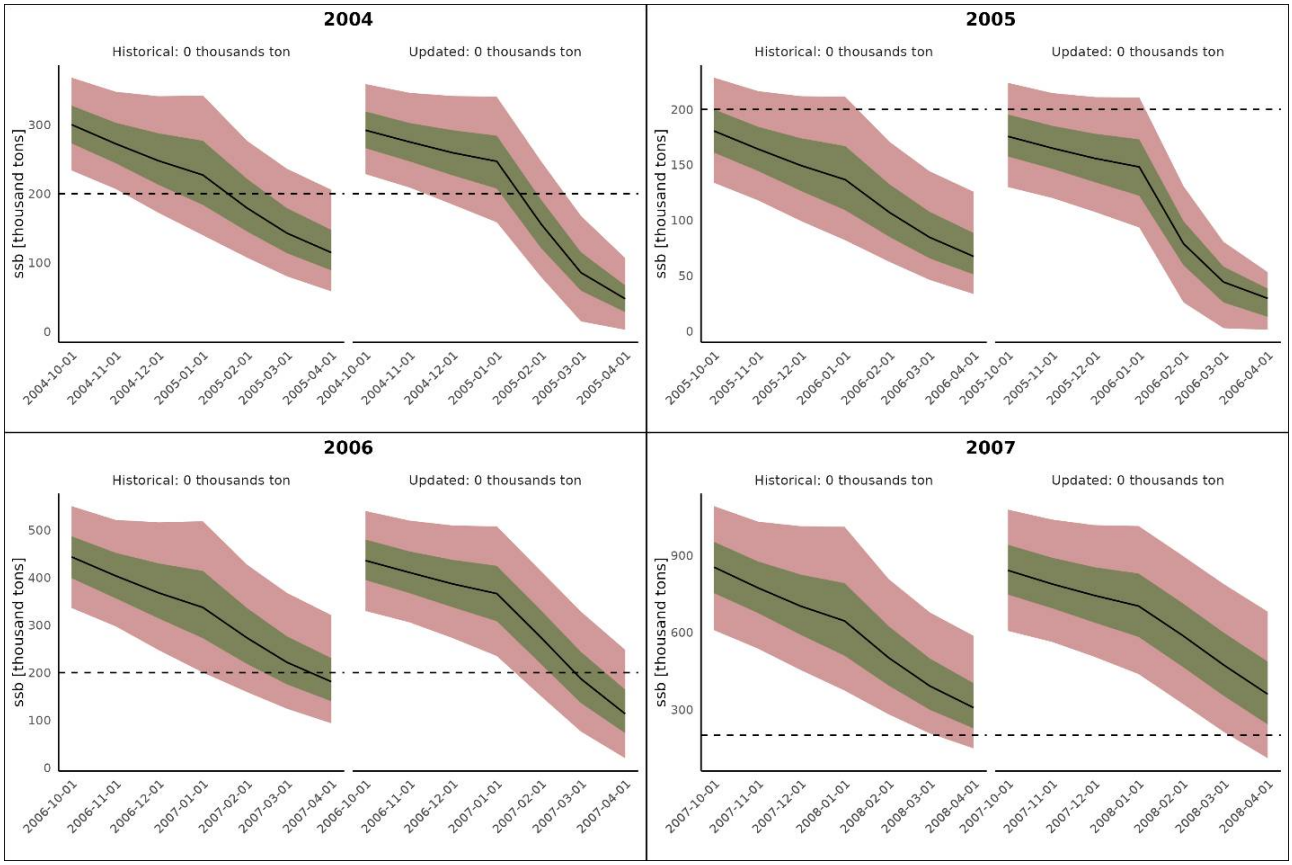
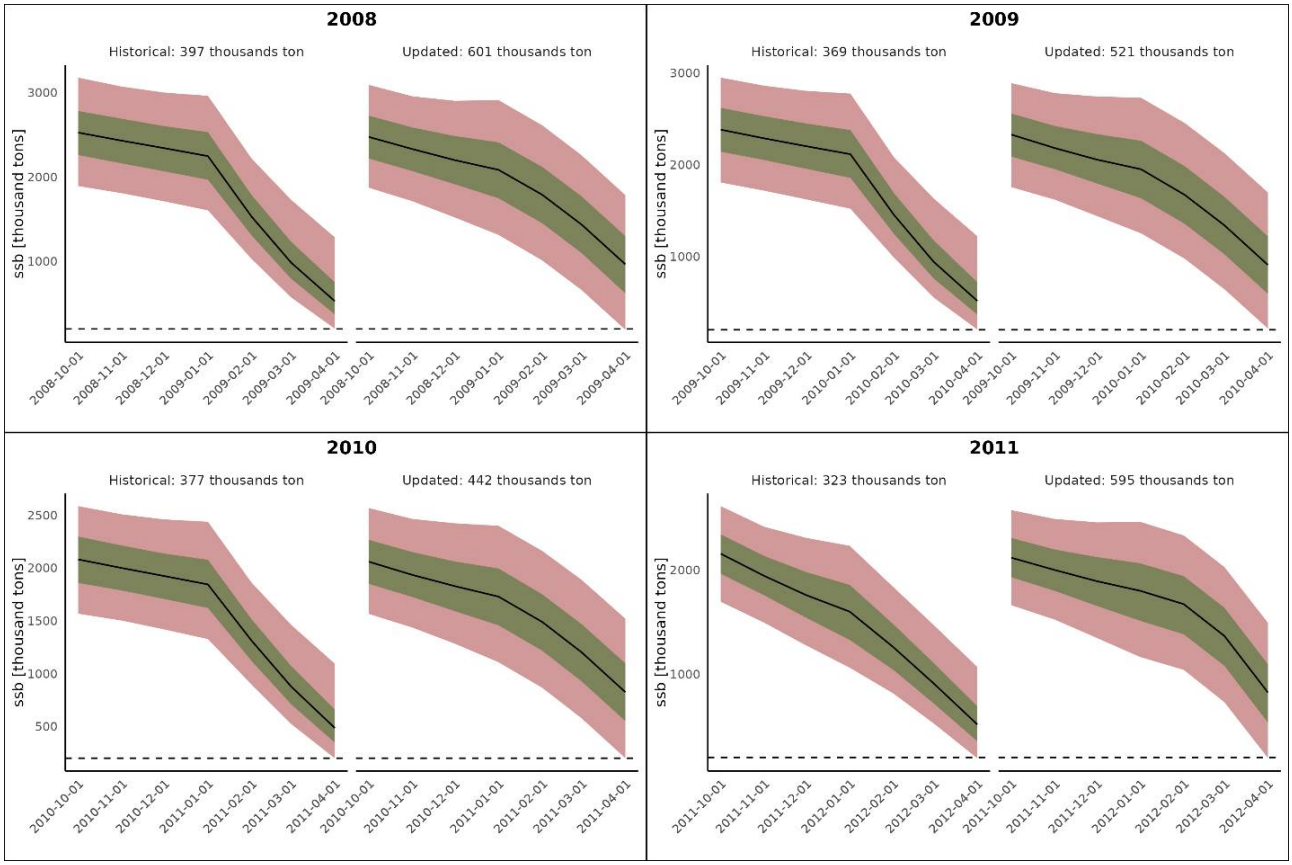
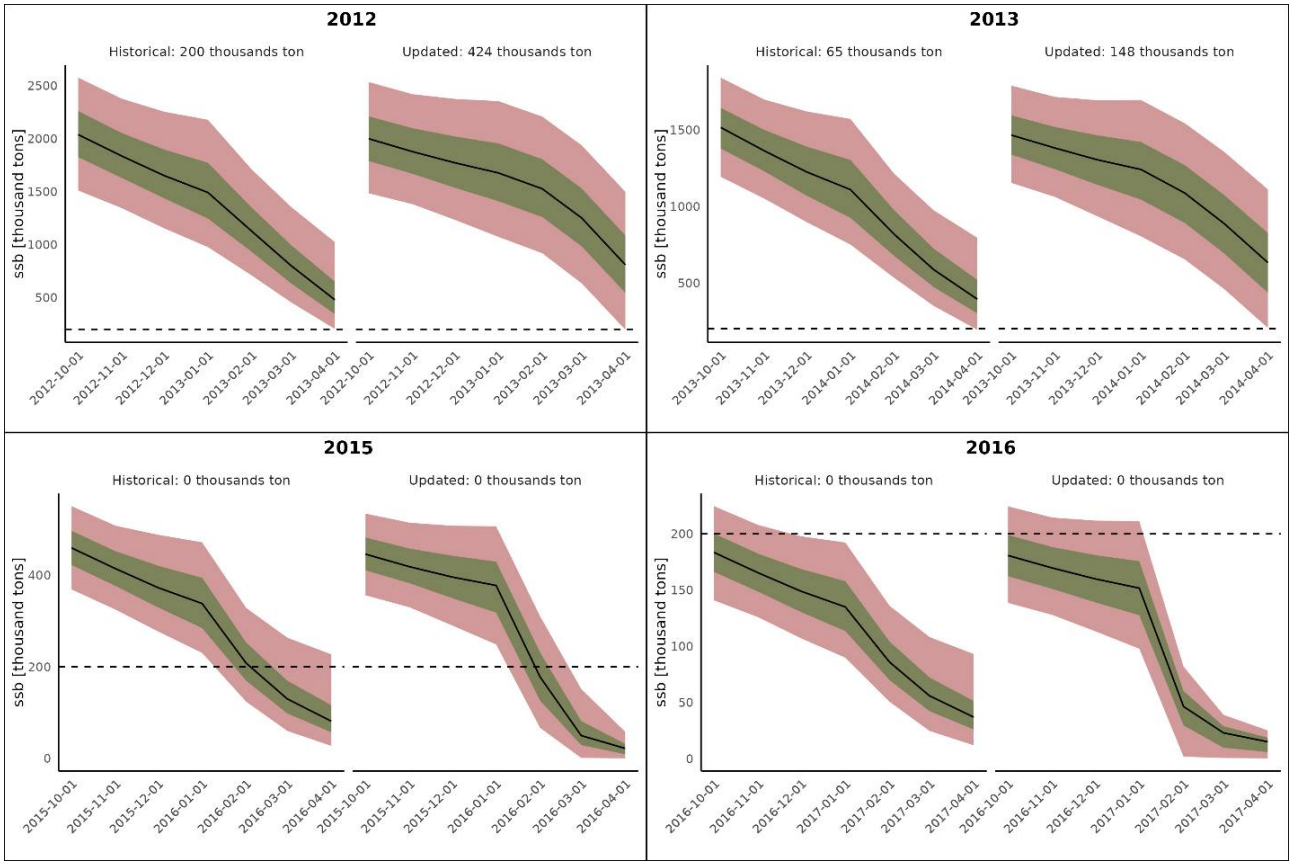
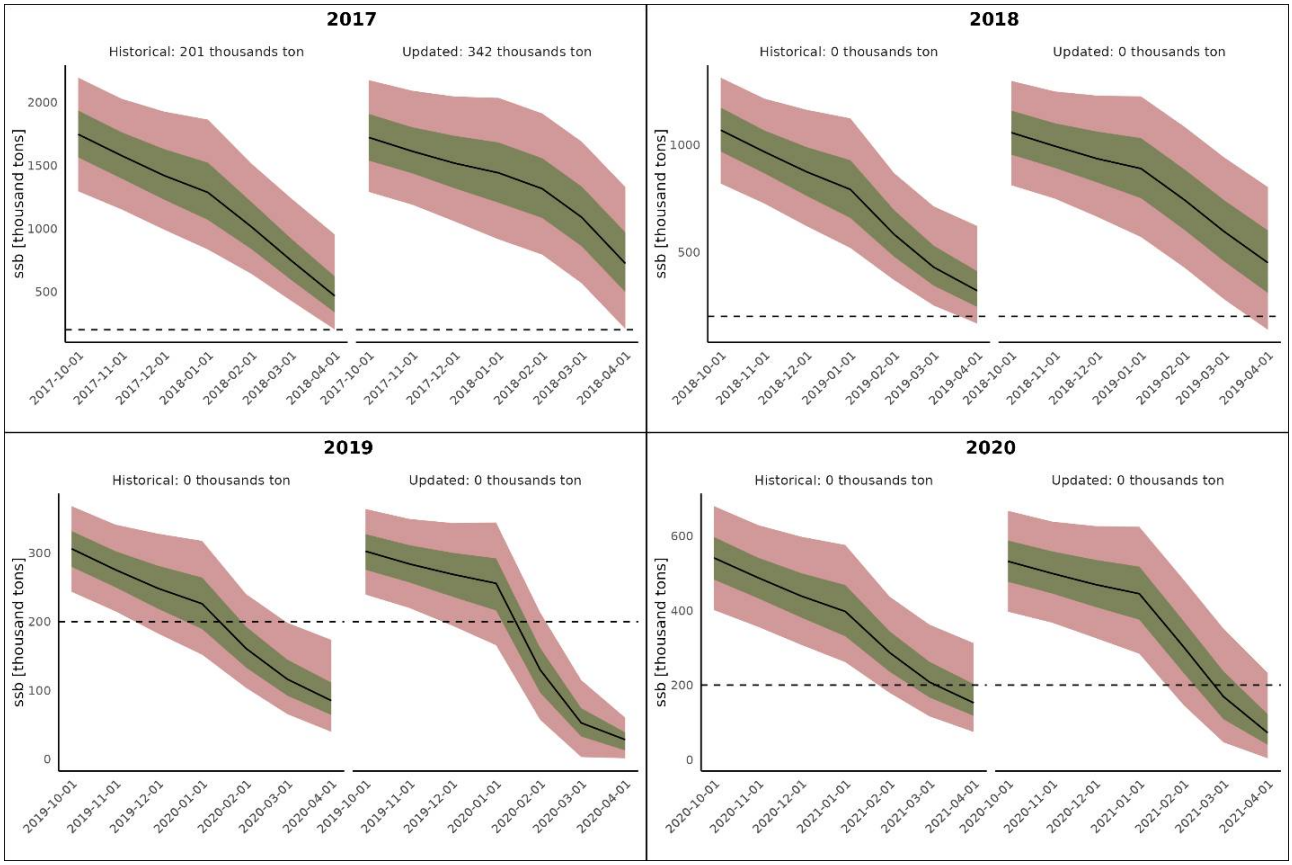


Figure A1. Proportion of immature cod in the Svalbard zone estimated by age group according to original configuration (period 1983-2004) and updated configuration inferred from the winter survey (period 2014-2023).


2004
Historical: 0 thousands ton
Updated: 0 thousands ton
2005
Historical: 0 thousands ton
Updated: 0 thousands ton
2006
Historical: 0 thousands ton
Updated: 0 thousands ton
2007
Historical: 0 thousands ton
Updated: 0 thousands ton
ssb [thousand tons]


2008
Historical: 397 thousands ton
Updated: 601 thousands ton
2009
Historical: 369 thousands ton
Updated: 521 thousands ton
2010
Historical: 377 thousands ton
Updated: 442 thousands ton
2011
Historical: 323 thousands ton
Updated: 595 thousands ton
ssb [thousand tons]


2012
Historical: 200 thousands ton
Updated: 424 thousands ton
2013
Historical: 65 thousands ton
Updated: 148 thousands ton
2015
Historical: 0 thousands ton
Updated: 0 thousands ton
2016
Historical: 0 thousands ton
Updated: 0 thousands ton
ssb [thousand tons]


2017
Historical: 201 thousands ton
Updated: 342 thousands ton
2018
Historical: 0 thousands ton
Updated: 0 thousands ton
2019
Historical: 0 thousands ton
Updated: 0 thousands ton
2020
Historical: 0 thousands ton
Updated: 0 thousands ton
ssb [thousand tons]

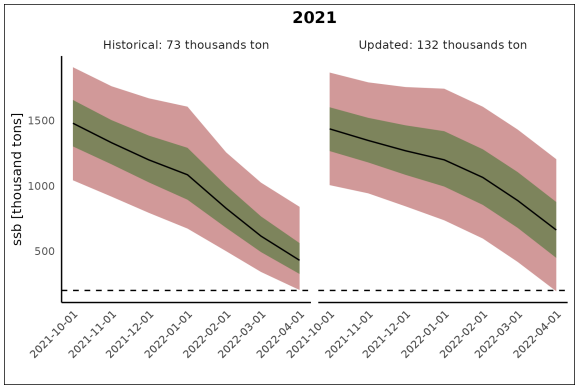


Figure A2. Comparison of original and updated (using 2023 configuration) forecast of maturing capelin from 1st October (end of survey) to 1st April (end of spawning). In the legend ‘historical’ gives original catch advice, and ‘updated’ catch advice with updated configuration. Note that advices given in 2014 and 2022 (for advice years 2015 and 2023) have not been compared since these original advices were adjusted.

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