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Assessment report for northern shrimp (*Pandalus borealis*) in the Barents Sea (ICES Subareas 1 and 2)

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Content

1 - Introduction

Northern shrimp (*Pandalus borealis*) in the Barents Sea (ICES Subareas 1 and 2), including the Svalbard fishery protection zone (FPZ) and coastal shrimp along the Norwegian coast north of 62°N, is considered as one stock. Norwegian and Russian vessels exploit the stock in the entire area, while vessels from other nations are restricted to the Svalbard FPZ and the “loophole” area.

Norwegian vessels initiated the fishery in 1970. As the fishery developed, vessels from several nations joined and landings increased rapidly (Figure 1). Vessels from Norway, Russia, Iceland, Greenland, Faroes, United Kingdom and the EU participate in this fishery on a regular basis. There is no overall total allowable catch (TAC) established for this stock but a separate TAC is set for the Russian Exclusive Economic Zone (EEZ). In the Norwegian EEZ and Svalbard FPZ, the fishery is only partly regulated by effort control. Licenses are required for the Russian and Norwegian vessels. In the Norwegian EEZ and Svalbard FPZ, the fishing activity of these license holders is constrained only by bycatch regulations whereas the activity of third country fleets operating in the Svalbard FPZ is also restricted by the number of effective fishing days and the number of vessels by country. The minimum legal stretched mesh size in the trawl is 35 mm. Bycatch is limited by mandatory sorting grids and by the temporary closing of areas where excessive bycatch of juvenile cod, haddock, Greenland halibut, redfish or shrimp <15 mm carapace length (CL) is registered.

1.1 - Catches

Catches have increased from a lowpoint of 19 248 t in 2013 to an average of 63 966 t in the past 5 years (Figure 1). Preliminary information for 2024 indicated significantly higher total catches compared to 2023. Catches in the fishery are assumed to be equivalent to reported landings.

Table 1: Recent catches in tonnes, as used for the assessment by fleet. Others include EU, Greenland, Iceland, Faroes and United Kingdom. Catches for 2024 are predicted based on preliminary reporting. All catches are based on reported landings.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024[1]
Norway	10 234	16 618	10 898	7 010	23 126	23 924	19 115	30 177	35 290	34 764	46 817
Russia	741	1 151	2 491	3 849	12 561	28 081	21 265	12 379	3 809	12 288	16 570
Others	9 988	16 252	17 359	19 582	20 653	21 576	17 999	13 085	20 481	25 595	19 720
Total catch	20 963	34 022	30 748	30 441	56 341	73 582	58 380	55 641	59 580	72 647	83 107

[1]Preliminary

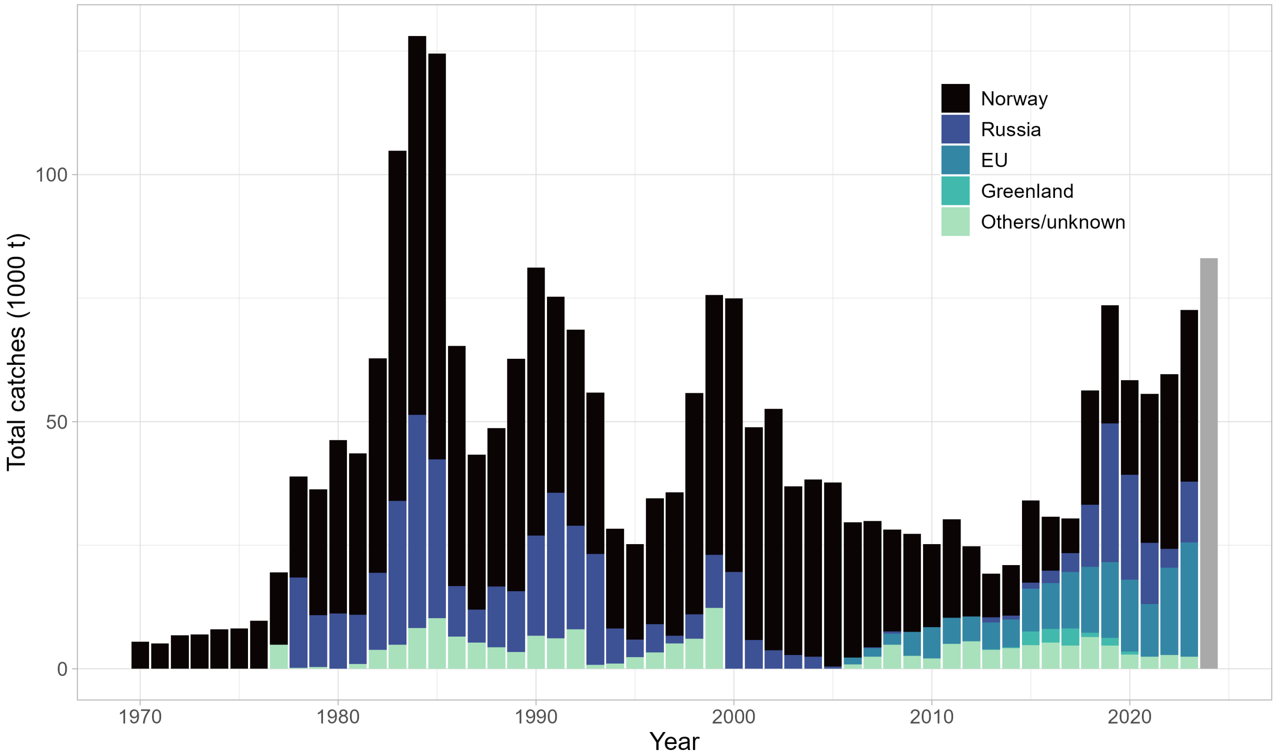

Figure 1: Total reported catches by country and year. Catches for 2024 are predicted based on preliminary reporting.

1.2 - Discards and bycatch

Discards of shrimp cannot be quantified but are believed to be small as the fishery is not limited by quotas. Bycatch rates of other species are estimated from at-sea inspections and research surveys and are corrected for differences in gear selection pattern, and raised with the corresponding shrimp catches from logbooks to give an overall bycatch estimate (Breivik *et al.*, 2017). Revised and updated discards estimates (1983–2017) of cod, haddock and redfish juveniles in the Norwegian commercial shrimp fishery in the Barents Sea were available in 2018. Since the introduction of the Nordmøre sorting grid in 1992, only small individuals of cod, haddock, Greenland halibut, and redfish, in the 5–25 cm size range, are caught as bycatch. Collecting bags, an extra codend mounted on the shrimp trawl for catching ground fish as bycatch, are being used by some EU vessels (ICES, 2022a).

1.3 - Ecosystem considerations

Since the 1980s, the Barents Sea has shifted from a situation with high fishing pressure, cold conditions and low demersal fish stock levels, to a state of high levels of demersal fish stocks, reduced fishing pressure and warmer conditions. A recent substantial decline of Atlantic cod (*Gadus morhua*) may, however, confirm a trend reversal and possibly reduce predation pressure on northern shrimp. More detailed information on ecosystem dynamics in the Barents Sea are provided in reports of the ICES Working Group on the Integrated Asessment of the Barents Sea (ICES, 2022b) and the Barents Sea ecosystem survey (Prozorkevich *et al.*, 2024).

2 - Input data

2.1 - Commercial fishery data

Information on catches by country were retrieved from the ICES database and complemented with catch information from the Norwegian landings register for the assessment year. Logbook data are normally available only from the Norwegian fleet. For 2020 - 2023, quarterly catch and effort data by ICES rectangle was received from Poland, Latvia, Lithuania and Estonia. In addition, information was provided by Russia, including information on catches in current year, catch distribution and standardized catch rates.

A major restructuring of the Norwegian shrimp fishing fleet towards fewer and larger vessels took place during the late-1990s through the early 2000s (Figure 2). Until 1996, the fishery was conducted using single trawls only. Double and triple trawls were then introduced. An individual vessel may alternate between single and multiple trawling depending on fishing conditions.

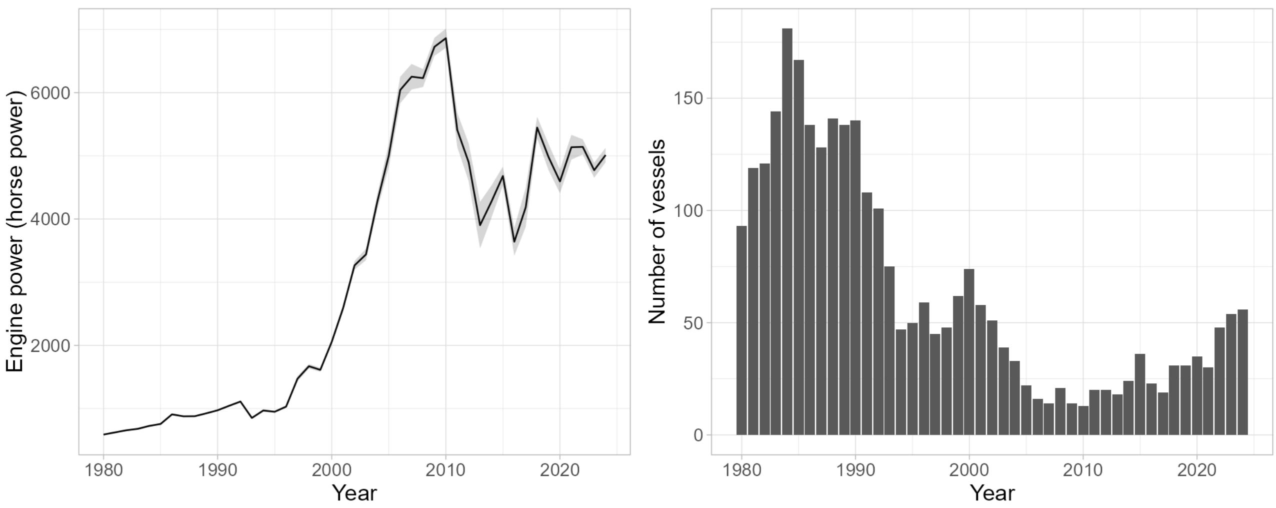

Figure 2: Mean engine power (HP) weighted by trawl-time (left) and number of vessels (right) in Norwegian fleet. Data are based on logbook registrations.

The fishery takes place throughout the year but can be seasonally restricted by ice conditions. Fishing activity occurs generally in March to October, with peak activity in May to August.

The fishery was originally conducted mainly in the central Barents Sea and on the Svalbard Shelf along with the Goose Bank (southeast Barents Sea). Norwegian logbook data since 2009 show decreased activity in the Hopen Deep and around Svalbard, coupled with increased effort further east in international waters (the “loophole”) (Figure 3). Information from the Norwegian industry points to decreasing catch rates and more frequent area closures due to bycatch of juvenile fish on the traditional shrimp fishing grounds as the main reasons for the observed change in fishing pattern.

Norwegian logbook data were used in a generalized additive mixed model (GAMM) to calculate a standardized index of catch per unit effort (CPUE) (ICES, 2022c). The GAMM used to derive the CPUE index was implemented in glmmTMB (Brooks *et al.*, 2017) and included the following variables: (1) vessel and (2) area (five survey strata) as random intercepts, (3) season (month) and (4) gear type (single, double or triple trawl) as categorical fixed effects, and vessel size (registered length) as continuous effect with a smooth spline (restricted to 3 knots). The underlying data combines logbook data with lower resolution prior to 2011 with electronic logbooks from 2011 onward. The approach estimation method was evaluated and revised during the last benchmark (ICES, 2022c), resolving prior robustness issues and resulting in a stable index (Figure 6). However, the expansion of reporting requirements to vessels below 15m since 2022 has increased substantially the number of observations from the coastal fleet that is mostly operating within the fjords. As the dynamics of inshore stock components are assumed to be not representative for the Barents Sea, all inshore ERS reportings were removed in this year's index estimation to avoid potential bias. This resulted in a minor revision of the index from last year's assessment, with a slightly more negative trend for the current year compared to when inshore catches were included.

The CPUE index is representative of the exploitable biomass of shrimp ≥15 mm CL, i.e. females and older males. The Norwegian logbook data on which the CPUE index is based represented historically fishing activity from most of the stock's distribution area. However, the fishery has contracted increasingly into a more limited area in the central Barents Sea in the last decade. Although in recent years the proportion of total catches taken by Norway has varied, it has remained between one third and more than half of the total catches.

The Russian fishery was mainly conducted in the open part of the Barents Sea and the Svalbard area, but later the main fishing grounds shifted eastward near coastal waters of the Novaya Zemlya Archipelago. Russian logbook data since 2023 show increased activity in international waters (the "loophole") (Figure 4). Catches peaked in 1983–1985 and varied in subsequent years (Figure 1). From 2005 onward, the Russian fishery for shrimp largely ceased and only rebounded 10 years later following a restructuring of the fleet.

A standardized CPUE index based estimated from Russian logbook data using a generalized additive mixed model (GLM) that takes area, depth, gear, and month into account. The index showed only minor fluctuations from 2017 to 2024. From a maximum in 2019 it decreased by 25% in 2024, but remains at the long-term average level (Figure 5). This standardized CPUE was not evaluated at the 2022 benchmark and is currently only used as auxilliary indicator in the assessment.

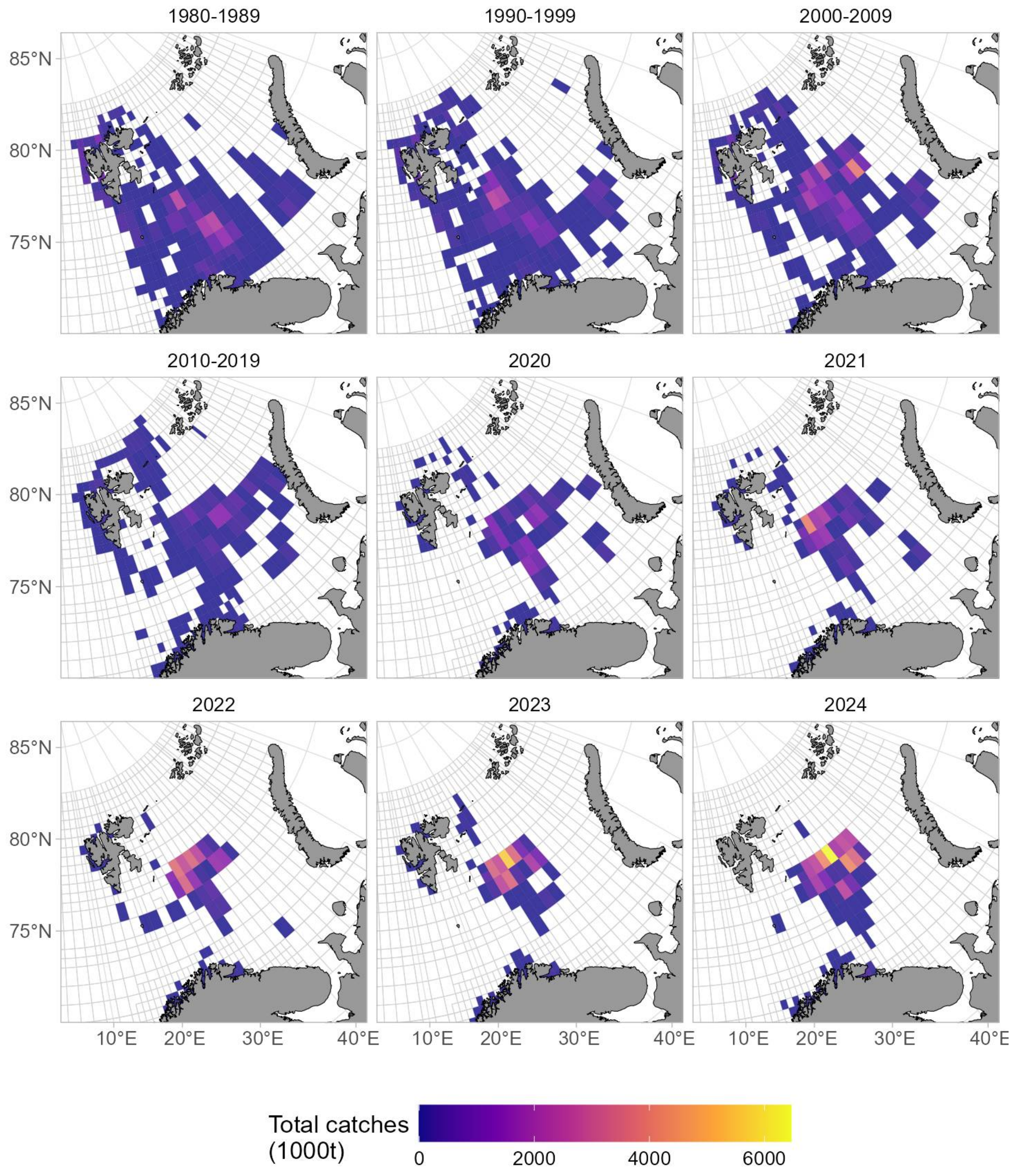

Figure 3: Distribution of annual catches by Norwegian vessels since 1980 based on logbook information. For periods before 2020, mean annual catches across a decade are shown. 2024 includes only data until October.

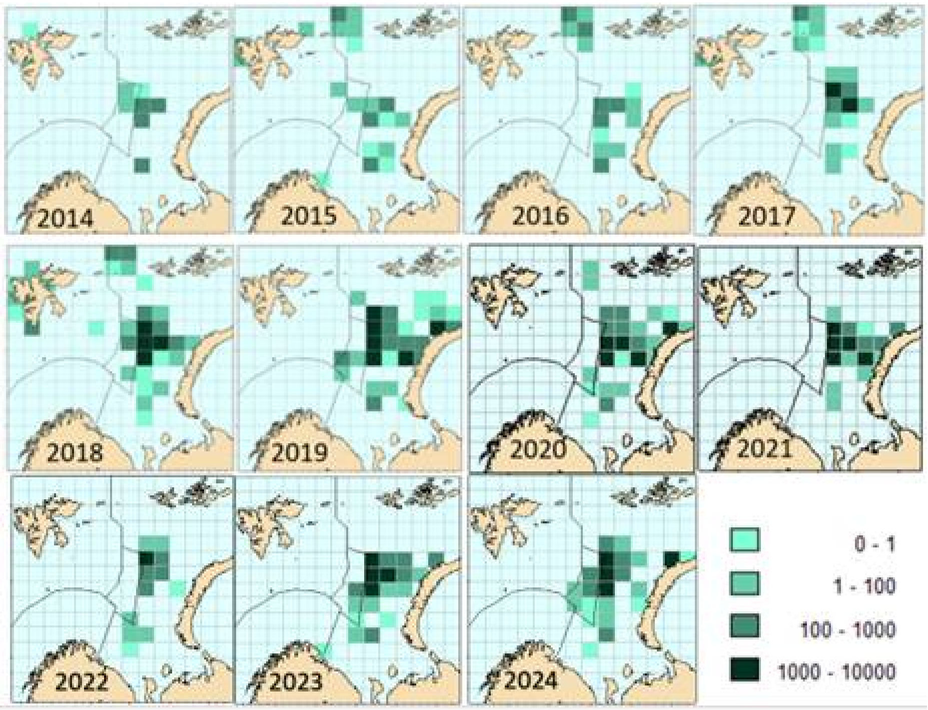

Figure 4: Distribution of annual catches by Russian vessels since 2014 based on logbook information. 2024 includes only data until October.

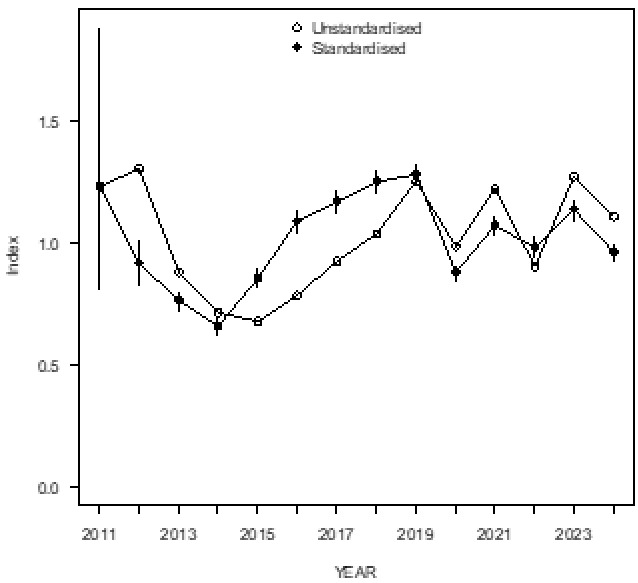

Figure 5: Dynamics of the standardized CPUE index based on Russian data.

2.2 - Research survey data

Russian and Norwegian surveys were conducted in their respective EEZs of the Barents Sea from 1984 to 2002 and 1982 to 2004, respectively, to assess the status of the northern shrimp stock. In 2004, these surveys were replaced by the joint Norwegian-Russian Barents Sea Ecosystem Survey (BESS) in August and September, which monitors shrimp along with a multitude of other ecosystem variables in the Barents Sea and around Svalbard (Prozorkevich *et al.*, 2024).

The biomass indices of the Norwegian shrimp and Russian surveys have fluctuated without trend over their respective time periods covered, and were combined in this year's assessment into one aggregate index (sum of annual biomass estimates in 1984–2002) (Figure 6). The BESS index has fluctuated without any directional trend over the past two decades and has decreased to an intermediate to low level in 2024. The spatial distribution of shrimp biomass has been relatively stable on a large scale over the recent survey period (Figure 7).

In general, the entire survey area of the ecosystem survey (Figure 7) is covered in all years, however, due to heavy ice conditions in 2014 the northern part of the area was not covered, and in 2020 and 2022, parts of the survey were not conducted or at a later stage due to technical problems with survey vessels. For 2024, data from the Russian EEZ were not available at the time of the assessment.

During the benchmark in 2022, estimation methods for the ecosystem survey index were evaluated to determine a more suitable approach for handling incomplete coverage (ICES, 2022c). A model-based approach was subsequently adopted to replace the prior design-based approach, using a GAMM implemented in the R-package sdmTMB (Anderson *et al.* , 2024) that includes spatio-temporal correlation. In the modelled index, missing coverage is predicted out of the estimated relationship between shrimp density and depth as well as the spatio-temporal random fields. The new method provides a robust approach that relies on established statistical methodology, provides uncertainty estimates, and improves on the past ad-hoc approaches to produce indices in situations with incomplete coverage. However, it should be noted that the BESS index includes undersized biomass due to inconsistencies in length data due to incomplete length sampling prior to 2022. The index is therefore not strictly representative of exploitable biomass and rather reflects trends in stock biomass.

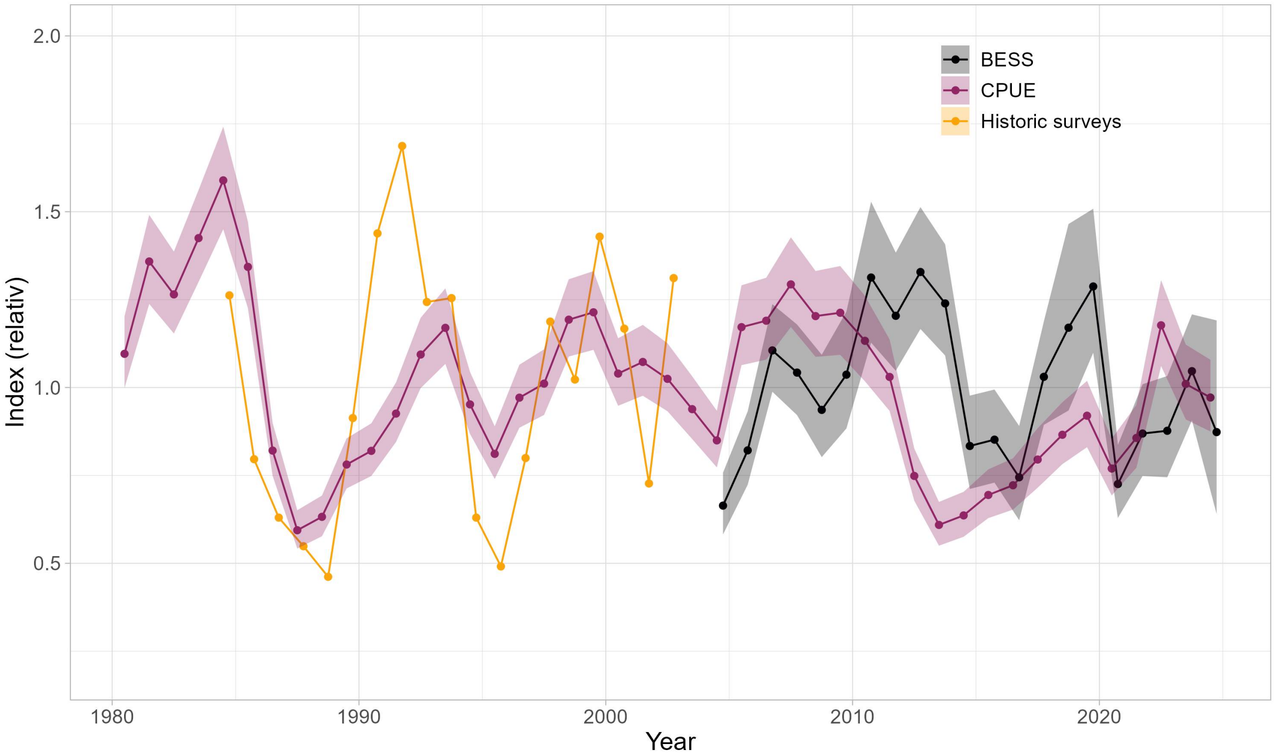

Figure 6: Indices of stock biomass from the (1) joint Russian-Norwegian Barents Sea ecosystem survey (BESS, since 2004), (2) Norwegian logbook data from the fishery (CPUE), and (3) a historic index based on the annual sum of Norwegian shrimp survey and the Russian survey (1984–2002). Lines show the mean estimates, the shaded area the 95% confidence interval. All indices were standardized to their respective mean.

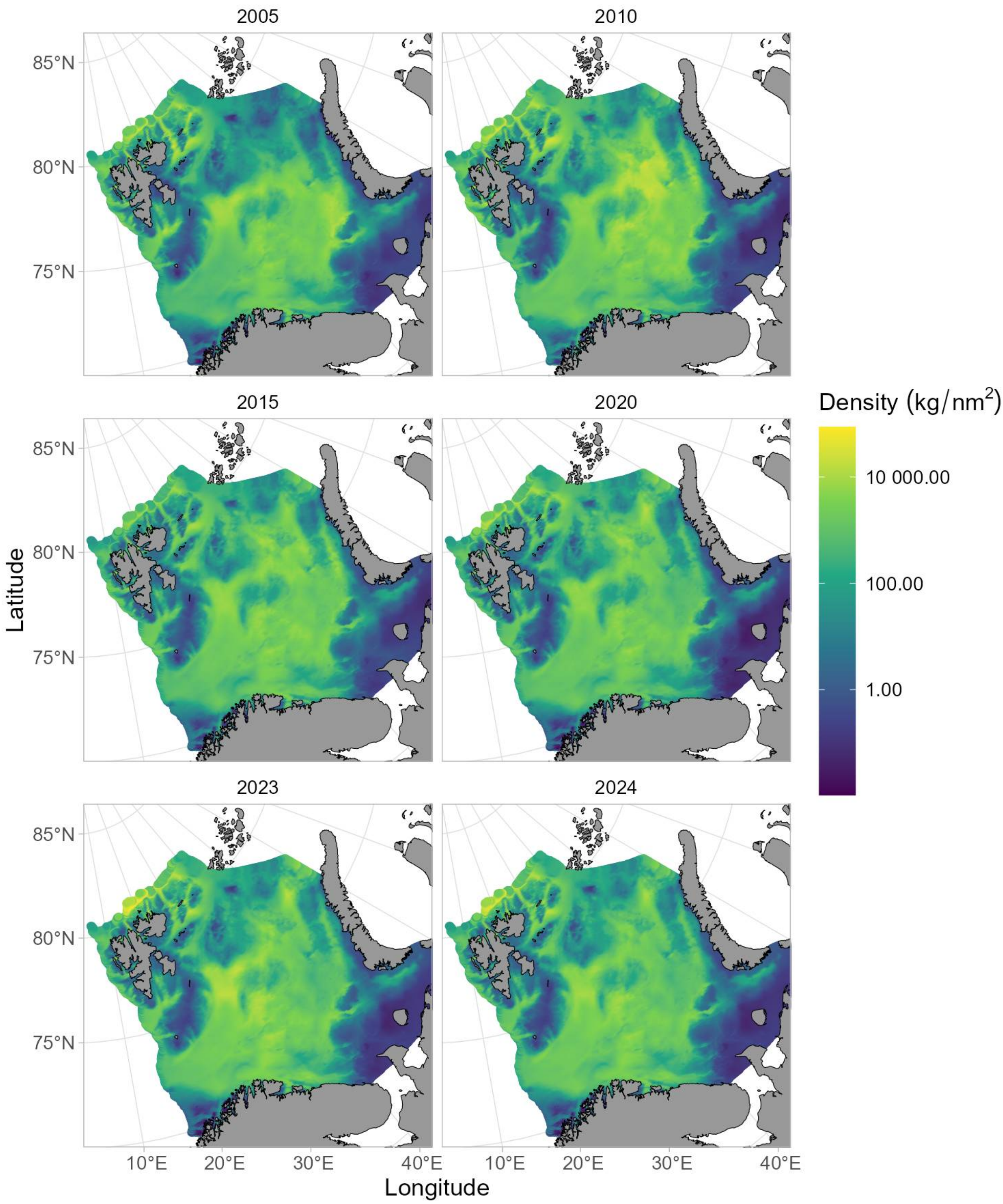

Figure 7: Spatial distribution of shrimp biomass based on ecosystem system survey data. Biomass is predicted with a GAMM including spatio-temporal correlation that was used to produce the standardized survey index.

2.3 - Recruitment indices

The benchmark in 2022 (ICES, 2022c) concluded that availability of length data from the joint ecosystem survey was too inconsistent and spatially incomplete for extracting reliable information about changes in size composition or recruitment.

2.4 - Reference points

Four reference points are considered: MSY $B_{trigger}$ and F_{MSY} representing the MSY approach, and B_{lim} and F_{lim} representing the precautionary approach. MSY $B_{trigger}$ is defined as 50% of B_{MSY}, and B_{lim} and F_{lim} as 30% and 170% of B_{MSY} and F_{MSY}, respectively. B_{MSY} and F_{MSY} are estimated directly in the assessment model.

3 - Assessment

The model is formulated in the state-space framework Surplus production in Continuous Time (SPiCT), implemented in the R package with the same name (Pedersen and Berg, 2017). Within this model, parameters relevant for the assessment and management of the stock are estimated, based on a stochastic version of a surplus-production model.

The configuration implemented in SPiCT in 2022 (ICES, 2022c) was used for the assessment. The model synthesized information from priors, four independent stock indices and the time series of total shrimp catches. The shape of the surplus production function was fixed to a Schaefer-type shape (shape parameter (*n*) = 2).Model settings were the same as those determined during the benchmark meeting, with exception of observation error priors and annual weighting added on the inputed stock indices, as well as a prior for growth rate *r* . Parameter estimates are presented in Table 2.

Table 2: Summary of parameter estimates: mean and 95% confidence intervals for selected parameters estimated in the 2024 assessment. Catchabilities are relative to the stock indices standardized to there mean and were multiplied by 1000 for display purposes.

Description	Parameter	Estimate	Low	High	Log_SE
MSY (kt)	*m*	133	50	352	4.891
Carrying capacity (kt)	*K*	1 321	549	3 178	7.186
Catchability CPUE	*q1*	0.862	0.319	2.328	-7.056
Catchability BESS	*q2*	0.903	0.334	2.440	-7.010
Catchability historic surveys	*q3*	0.834	0.305	2.277	-7.089
Observation error CPUE	*sdi1*	0.148	0.111	0.199	-1.908
Observation error BESS	*sdi2*	0.122	0.082	0.183	-2.100
Observation error historic surveys	*sdi3*	0.244	0.187	0.317	-1.412

3.1 - Input time series

The input data consisted of standardized stock indices from time series of fisheries-dependent logbook data for 1980–2024 and trawl-survey biomass indices for 1982–2004, 1984–2005 and for 2004–2023 (Figure 6). These indices were scaled to exploitable stock biomass by individual catchability parameters, *q*, with lognormal observation errors. Total reported catches in ICES Division 1 and 2 since 1970 were used to estimate removals (Figure 1) and, thus, catches were not treated as error-free values. Biomass, *B*, was estimated relative to the biomass that would yield Maximum Sustainable Yield, B_{MSY}. The estimated fishing mortality, *F*, refers to the rate of removal of exploitable biomass by fishing and is scaled to the fishing mortality at MSY, F_{MSY}. Model specification, fitting procedure and diagnostics followed the standard recommendations ICES (2024).

3.2 - Priors

Priors were defined during the benchmark in 2022 for carrying capacity (*K*) and initial depletion (*B0/K*) based on a priori knowledge on stock density and historic fishing pressure. To address the issues of low weighting of the survey indices and high dependency on the *K* prior - as identified in last year’s report (Hvingel and Zimmermann, 2024) - priors on index observation uncertainty and population growth (*r*), respectively, were introduced. Prior and posterior distributions are shown in Figure 8.

For carrying capacity, a log-normal input prior (7.15 mean ±0.5 SD) was constructed based on the estimates of suitable shrimp habitat in the Barents Sea and carrying capacity in the West Greenland shrimp stock (ICES, 2022c). West Greenland shrimp are comparable to Barents Sea shrimp because of a similar environment, providing a reference value for likely densities at carrying capacity. Together with information habitat size and relative habitat quality, this provided the basis for the *K* prior. In contrast to past assessments, the *K* prior was biased-corrected to account for the long upper tail of the log-normal distribution. The *r* prior was based on information from the meta database www.sealifebase.ca that aggregates information from existing assessment of northern shrimp (-0.79 ±0.5), implemented with a bias-corrected mean. The prior for the initial exploitation level (-0.29 ±0.25, corresponding to a mean of 75% depletion), on the other hand, was based on information on the historic fishing landings (Melaa *et al.*, 2022) from the Barents Sea prior to the time series included in the assessment.

In this year's assessment, the standard errors from the GAMMs used to estimate standardized stock indices from the BESS and commercial CPUE data were used to define the priors for the observation errors in SPiCT. The goal was to inform the assessment model about the uncertainty of the stock indices using extrinsic information from the index estimation and, thus, address the issue that the assessment model gave very low weight to the BESS index in the past. For both the CPUE index and the BESS index, the mean estimated standard error of the indices across the respective time series was taken as proxy for CV and therefore set as mean of the observation error prior. For the historic survey time series, no uncertainty estimates were available and, thus, an arbitrary prior (log(0.2) mean ± 0.2 SD) was used for the observation error. Furthermore, because the mean standard error of the CPUE index was considered too low compared to the BESS index, it was multiplied with three. This represents an ad-hoc solution that requires further investigation into the low uncertainty of the CPUE index. In addition, the prior for catch observation error was set to log(0.1) as default, and subsequently the link between observation and process errors (alpha and beta parameters) was deactivated as recommended by ICES (ICES, 2024).

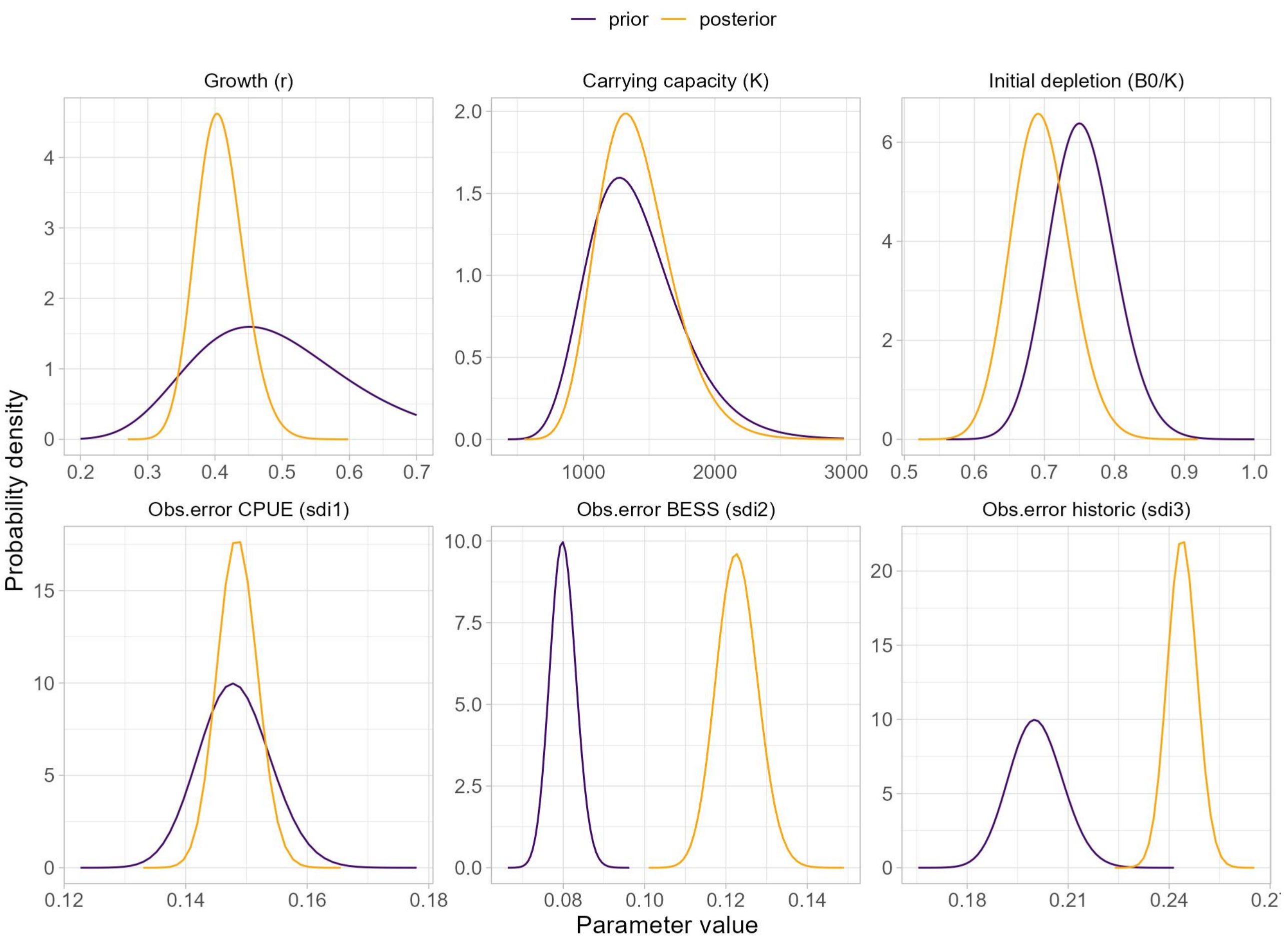

Figure 8: Prior and posterior distribution for carrying capacity K, growth rate r, initial depletion B0/K, and observation errors of commercial CPUE, BESS historic surveys indices.

3.3 - Model performance

The model was validated and performed generally well, in line with the in-depth exploration and sensitivity analysis conducted during the benchmark (ICES, 2022c). The model converged, was stable (<1% deviating estimates in jitter analysis), showed very little retrospective bias (Figure 9), had low mean absolute scale error (MASE <1) (Figure 10), and fulfilled most acceptance criteria in terms of residual patterns of observation and process errors (see annex) and uncertainty. Minor violations were caused by relatively large uncertainty in the F/F_{MSY} estimates, reflecting the lack of contrast in the time series, and correlated one-step-ahead residuals of the stock indices.

The observation error priors and annual multiplier introduced in this year’s assessment resolved the previous issue of problematic residual patterns and little to no weight given to the survey indices, instead balancing the weighting between BESS and CPUE index. However, this only shifted the minor issue with the residual patterns of input indices from the survey indices (Hvingel and Zimmermann, 2024) to the CPUE index. Although the changes implemented in this year’s assessment reduce the extent of previous issue by reducing the dominance of the CPUE index, the model is not capable of fully resolving the diverging trends of survey and CPUE indices in parts of the time series. Potential reasons are that the CPUE index currently does not account sufficiently well for technological creep and spatial contractions in the fishery, underlining the need for further investigations into the CPUE standardization.

The sensitivity of the stock and parameter estimates was explored during the benchmark in 2022 (ICES, 2022c). The analysis showed that the prior definition for initial depletion had no impact on the perception of stock status. This conclusion still applies and includes also the new prior on *r*. However, as noted in the benchmark report, there is some sensitivity of the stock trends to the mean of the *K* prior. While not resulting in a clear impact on the state of the stock, this indicates nevertheless that the definition of the *K* prior is a key element of the assessment and should be therefore carefully re-evaluated in the future.

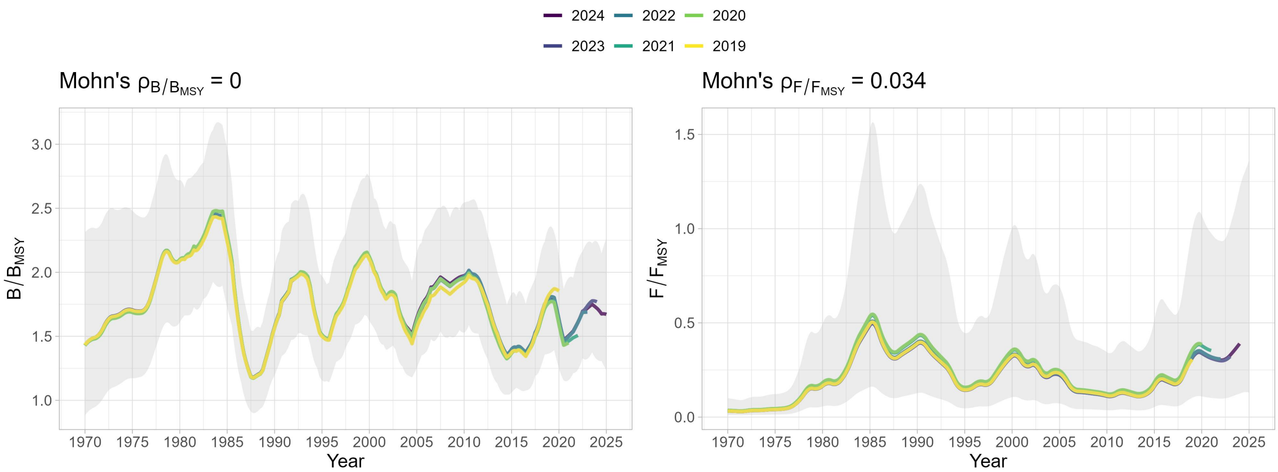

Figure 9: Retrospective analysis of the assessment model with 5 peels back in time from the current assessment year. Shown are resulting estimates in F/F_{MSY} and B/B_{MSY} with their respective Mohn's rho values.

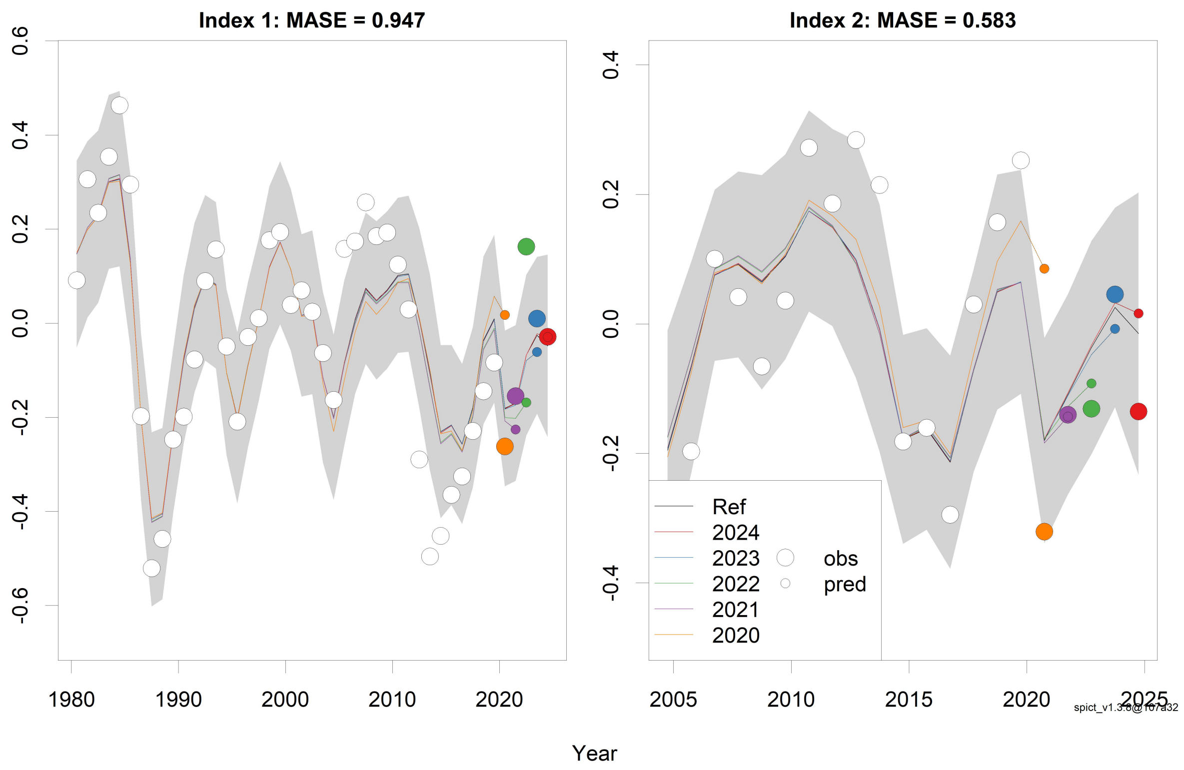

Figure 10: Hindcast of the assessment models for the stock indices from commercial CPUE (index 1) and BESS (index 2) with 5 years back in time from the current assessment year. Shown are observed index estimates vs. model predictions, and the corresponding MASE.

3.4 - Stock size and fishing mortality

Exploitable stock biomass was estimated to above B_{MSY} for the entire time series since 1970 (Figure 11). The lowest biomass level in the mid-1980s occurred following some years with high catches. Since then, the stock has varied on a stably high level. The corresponding mean estimate of fishing mortality has remained below F_{MSY} throughout the history of the fishery, with only three periods during the 1980s, around 2000 and since 2018 that the estimates indicate a (low) probability of exceeding F_{MSY}. For assessment year 2024, there is less than 5% probability that fishing mortality was above F_{MSY} and less than 1% probability that exploitable biomass was below MSY $B_{trigger}$ in the beginning of 2025 (Table 3).

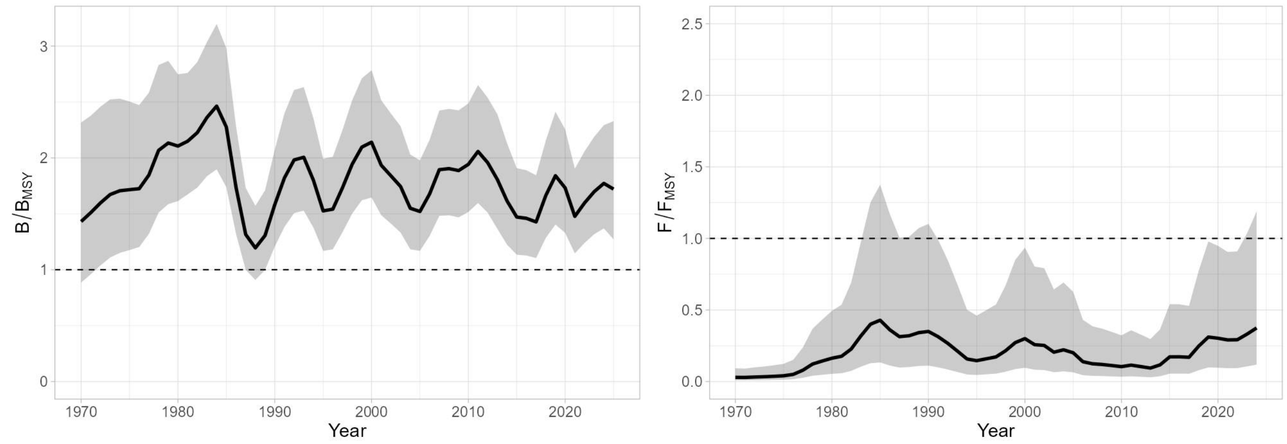

Figure 11: Estimated relative biomass (B/BMSY) and fishing mortality (F/FMSY) for 1970-2024. Solid lines represent the mean estimates, shaded surfaces the 95% confidence intervals. BMSY and FMSY are indicated with dashed lines.

Table 3: Estimates of relative exploitable stock biomass and fishing mortality as well as exceeding reference points in 2024 and 2025 at the beginning of each year.

	2024	2025
Exploitable stock biomass (B/B_{MSY})	1.77	1.72
Fishing mortality (F/F_{MSY})	0.36	0.72
Probability of falling below MSY $B_{trigger}$	0.0%	0.0%
Probability of falling below B_{lim}	0.0%	0.0%
Probability of exceeding F_{MSY}	4.0%	29.4%
Probability of exceeding F_{lim}	0.4%	7.8%

3.5 - Forecast and management plan

An intermediate year catch constraint based on the predicted catches for 2024 was used to forecast the catch scenarios in SPiCT. The forecasts for all catch scenarios were produced with the manage function in SPiCT for the advice period 2025-2026, including the predicted catch in 2024 as catch constraint for the intermediate year. For the advice, a short-term forecast is produced from the fitted stock assessment model using the fractile rule (35th percentile).

A management strategy evaluation for shrimp in the Barents Sea was conducted in 2024 (Trochta *et al.*, 2024) and four of the evaluated harvest control rules (HCR) were proposed as suitable basis for a management plan (IMR-PINRO, 2024). All four accepted HCRs used F_{MSY} or a fraction (90 or 80%) thereof as target *F* and a linear decrease of *F* below MSY $B_{trigger}$ (0.5 B_{MSY}) to zero at B_{lim} (0.3 B_{MSY}). The management plan was discussed at the autumn meeting of the Norwegian-Russian fisheries commission in 2024, but no HCR was adopted. The current advice for shrimp in the Barents Sea was therefore produced on a generic basis, using a precautionary MSY approach. However, the previously used F_{MSY} mode was replaced with the 35th percentiles of the catch, F/F_{MSY} and B/B_{MSY} distributions under F_{MSY}, following recommendation of ICES on catch advice for stocks using a SPiCT assessment (Berg *et al.*, 2021). For comparison, additional catch scenarios presented are fishing mortality at F_{MSY} (mean of catch distribution), the same level as in assessment year 2024, and zero fishing. The differences between the precautionary MSY approach and fishing at F_{MSY} are minor (Table 4) and both would imply a substantial increase in fishing pressure, more than doubling the current total catch.

Table 4: Predictions of risk and stock status associated with optional catch levels for 2024. Catches are in thousand tonnes, exploitable biomass and fishing mortality relative values, and risks are percentages. Estimates of exploitable biomass are for the beginning of the year after the advice year, whereas fishing mortalities are the mean of the advice year.

Scenario	Catch	B_{2026}/B_{MSY}	F_{2025}/F_{MSY}	% risk of $B_{2026} < B_{lim}$	% risk of $B_{2026} <$ MSY $B_{trigger}$	% risk of $F_{2025} > F_{MSY}$	% risk of $F_{2025} > F_{lim}$
Precautionary MSY approach*	150	1.60	0.72	0.0%	0.0%	30.2%	8.6%
$F_{2025} = F_{MSY}$	203	1.53	1.00	0.0%	0.0%	50.0%	19.9%
$F_{2025} = F_{2024}$	82	1.69	0.38	0.0%	0.0%	6.4%	0.9%
$F_{2025} = 0$	0	1.81	0.00	0.0%	0.0%	0.0%	0.0%

* 35th percentiles of biomass, fishing mortality and catch distribution under $F=F_{MSY}$, given the constraint of predicted catches for the assessment year.

4 - Environmental and other considerations

4.1 - Temperature

In the ecosystem survey, shrimps were only caught in areas where bottom temperatures were above 0°C. Highest shrimp densities were observed between zero and 4°C, while the limit of their upper temperature preference appears to lie at about 6-8°C. Although temperature is a likely driver for stock dynamics and distribution, no relationship of temperature with observed catch rates or stock biomass could be found during analysis conducted at the benchmark (ICES, 2022c). Further investigations of environmental drivers of shrimp distribution and abundance are necessary.

4.2 - Predation

Both stock development and the rate at which changes might take place can be affected by changes in predation, in particular by Atlantic cod, which has been documented as capable of consuming large amounts of shrimp. The relationship between shrimp biomass and cod biomass has been investigated during the benchmark but was not found to be significant given the available data (ICES, 2022c). The cod stock in the Barents Sea increased to historically very high levels during the past decade but has since decreased substantially in a significant trend reversal, providing a strong contrast for further analysis. As predator biomass may not be representative of predation pressure, further investigations into shrimp consumption by cod and potential impacts on stock dynamics are recommended.

4.3 - Recruitment, and reaction time of the assessment model

The model used is best at projecting trends in stock development but estimates and uses long-term averages of stock dynamic parameters. Large and/or sudden changes in recruitment or mortality may therefore be underestimated in model predictions.

5 - Research recommendations

- The fishery has expanded since 2014 and catches by countries other than Norway have increased to account for more than 50% of the total in most years. In 2016, NIPAG therefore recommended that available data (logbook data and catch samples) from the participating nations be made available for the assessment. An ICES data call has been made and some parties have now provided aggregated data on total catch and effort. Because of the low resolution of the data and short time series, it is currently not suitable for producing a standardized LPUE index and has therefore been of limited use in the assessment work. Further data requests and analysis of available data sources, including RDBES, are recommended. Receiving good information on catches of the EU in the assessment year would be of particular importance, considering their increased importance in the fishery.
- During the 2024 assessment, the weighting issue that resulted in negligible influence of the BESS index on stock estimates has been resolved, resulting in a more balanced weighting of stock indices. Considering that the survey coverage of the stock is comprehensive and representative, this is considered a major improvement. However, the lack of alignment between the trends of survey and commercial CPUE indices remains a potential issue for the assessment and a source of uncertainty. It is therefore recommended to continue the re-evaluation of stock indices from the 2022 benchmark, focusing on 1) the standardization of commercial CPUE over time, especially in light of a spatial contraction of the fishery that is not fully accounted for in the current index; 2) the potential use of data from the demersal fish survey in winter for a stock index to provide relevant information on the stock development within the assessment year (ICES, 2022c), especially given that BESS data is often still incomplete at the time of the assessment; and 3) re-estimate the historic survey index from the original Norwegian and Russian shrimp survey data to standardize methodology, increase comparability with the BESS index and produce uncertainty estimates. Furthermore, the SPiCT option of including fishing effort as input time series, replacing the CPUE index, should be explored.
- Despite the long time series of the assessment, the lack of contrast causes a dependency on informative priors. The carrying capacity prior in particular has a relevant effect on stock estimates. The prior definition and the sensitivity of the assessment to them should be therefore routinely evaluated. Furthermore, it is recommended to test a loosening of priors, notably carrying capacity. The introduction of a prior on population growth in this year’s assessment was a first step to reduce the importance of a prior for carrying capacity.
- The seasonality of the fishery is currently not included in the assessment model, although SPiCT is a continuous time framework that allows for modelling seasonality of catches explicitly. The current configuration sets the timing of the stock indices to the month of the year where they, in average, originate from, but treats catches as annual, discrete quantity. However, most fishing activity takes place in summer, creating strong fluctuations in fishing pressure throughout the year that should be accounted for. Further analysis of the demersal fish survey in winter could provide insights on the in-year dynamics of the stock, as it provides a fishery-independent data early in the year before the fishery takes place, whereas the BESS survey in autumn reflects the state of the stock after a large proportion of the annual catches have been taken.
- During the 2022 benchmark, it was recommended to investigate further the predator-prey relationship between shrimp and cod, including available data from cod stomach sampling. This recommendation has gained relevance since then due to the significant decrease of the cod stock, possibly reducing the predation pressure and counteracting an increase in fishing activity. Estimating overlap between shrimp and cod

distribution as well as shrimp consumption of cod and incorporating this information into the assessment could result in a relevant improvement of the assessment quality and provide a stepping stone towards a more ecosystem-based management of the stock.

- Only the exploitable biomass of the stock is currently assessed, cohort and recruitment dynamics remain unaccounted for. At the 2022 benchmark, it was concluded that the available survey information was insufficient as a basis for a recruitment index. However, following improved shrimp sampling on the BESS in recent years, this conclusion should be re-evaluated. Further, other options to incorporate information on population dynamics into the assessment should be investigated, for instance in form of size-based indicators. Catch sampling could in this context provide relevant data and should be re-considered.
- The current stock definition includes all shrimp north of 62ºN. Besides shrimp in the Barents Sea, this also covers inshore populations along the Norwegian coast and inside of fjords, as well as the shelf edges north and west of Svalbard. Especially the latter should likely be treated as separate stock components that with their own dynamics, possibly at the level of each fjord. Furthermore, there are clear distinctions in the fleet structure and dynamics between the large freezer vessels fishing offshore in the Barents Sea, and the smaller coastal vessels producing mostly fresh cooked shrimp for the local market. Although catches from the coastal component are marginal compared to the Barents Sea, combining information from the different areas and stock components might increase the risk for biased signals. This was underlined by the impact of increased logbook reporting from the smaller coastal vessels on the CPUE index. Further research of the stock structure and exploring separate assessments or area-based approaches to differentiate the stock and fleet components better is therefore recommended.
- A recent study highlighted that maximum economic yield for the stock is likely significantly lower than *MSY* (Lancker *et al.* , 2023), emphasising that economic factors are likely limiting the fishery. The economic drivers of fisheries dynamics could provide insights on economically optimal harvest strategies. The management strategy evaluation conducted in 2024 (Trochta *et al.* , 2024) provided a comprehensive simulation framework to test management strategies but did not include economic components. It is therefore recommended to expand the simulation framework with an economics component to improve our understanding of the fishery dynamics and develop economic performance indicators and reference points.

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7 - Annex

7.1 - Input data

Table 5: Catches in tonnes, as used for the assessment by fleet. Catches for the final year are based on preliminary information, and country-specific information only available from 2000 (except for Norway and Russia).

Year	Norway	Russia	EU	Greenland	Others/unknown
1970	5508	0	0	0	0
1971	5116	0	0	0	26
1972	6772	0	0	0	0
1973	6921	0	0	0	0
1974	8008	0	0	0	0
1975	8197	0	0	0	2
1976	9752	0	0	0	0
1977	14700	0	0	0	4854
1978	20484	18270	0	0	189
1979	25435	10474	0	0	390
1980	35061	11219	0	0	0
1981	32713	9886	0	0	1011
1982	43451	15552	0	0	3835
1983	70798	29105	0	0	4903
1984	76636	43180	0	0	8246
1985	82123	32104	0	0	10262
1986	48569	10216	0	0	6538
1987	31353	6690	0	0	5324
1988	32021	12320	0	0	4348
1989	47064	12252	0	0	3432
1990	54182	20295	0	0	6687
1991	39663	29434	0	0	6156
1992	39657	20944	0	0	8021
1993	32663	22397	0	0	806
1994	20162	7108	0	0	1063
1995	19337	3564	0	0	2319
1996	25445	5747	0	0	3320
1997	29079	1493	0	0	5163
1998	44792	4895	0	0	6103
1999	52612	10765	0	0	12293
2000	55333	19596	0	0	0
2001	43031	5846	0	0	0
2002	48799	3790	0	0	0
2003	34172	2776	0	0	0
2004	35918	2410	0	0	0

Year	Norway	Russia	EU	Greenland	Others/unknown
2005	37253	435	0	0	0
2006	27352	4	1365	0	906
2007	25558	192	1729	0	2451
2008	20662	417	2207	0	4902
2009	19784	0	4903	0	2586
2010	16776	0	6309	0	2110
2011	19928	0	5292	0	5006
2012	14159	5	5073	0	5526
2013	8846	1067	5416	95	3824
2014	10234	741	5667	149	4173
2015	16618	1151	8665	2774	4813
2016	10898	2491	9275	2821	5264
2017	7010	3849	11406	3487	4689
2018	23126	12561	13394	803	6457
2019	23925	28081	15342	1566	4669
2020	19116	21265	14489	633	2878
2021	30177	12379	10638	0	2448
2022	35290	3809	17662	0	2819
2023	34764	12288	23179	0	2416
2024	46817	16570	0	0	19721

Table 6: Northern shrimp in subareas 1 and 2. Input data for the stock assessment model.

Year	BESS index	Historic index	CPUE index	Catch
1970				6
1971				5
1972				7
1973				7
1974				8
1975				8
1976				10
1977				20
1978				39
1979				36
1980			1.10	46
1981			1.36	44
1982			1.26	63
1983			1.42	105
1984		1.26	1.59	128
1985		0.80	1.34	124
1986		0.63	0.82	65
1987		0.55	0.59	43

Year	BESS index	Historic index	CPUE index	Catch
1988		0.46	0.63	49
1989		0.91	0.78	63
1990		1.44	0.82	81
1991		1.69	0.93	75
1992		1.24	1.09	69
1993		1.25	1.17	56
1994		0.63	0.95	28
1995		0.49	0.81	25
1996		0.80	0.97	35
1997		1.19	1.01	36
1998		1.02	1.19	56
1999		1.43	1.21	76
2000		1.17	1.04	81
2001		0.73	1.07	57
2002		1.31	1.02	61
2003			0.94	39
2004	0.66		0.85	43
2005	0.82		1.17	43
2006	1.11		1.19	30
2007	1.04		1.29	30
2008	0.94		1.20	28
2009	1.04		1.21	27
2010	1.31		1.13	25
2011	1.20		1.03	30
2012	1.33		0.75	25
2013	1.24		0.61	19
2014	0.83		0.64	21
2015	0.85		0.69	34
2016	0.74		0.72	31
2017	1.03		0.80	30
2018	1.17		0.87	56
2019	1.29		0.92	74
2020	0.73		0.77	58
2021	0.87		0.86	56
2022	0.88		1.18	60
2023	1.05		1.01	73
2024	0.87		0.97	83

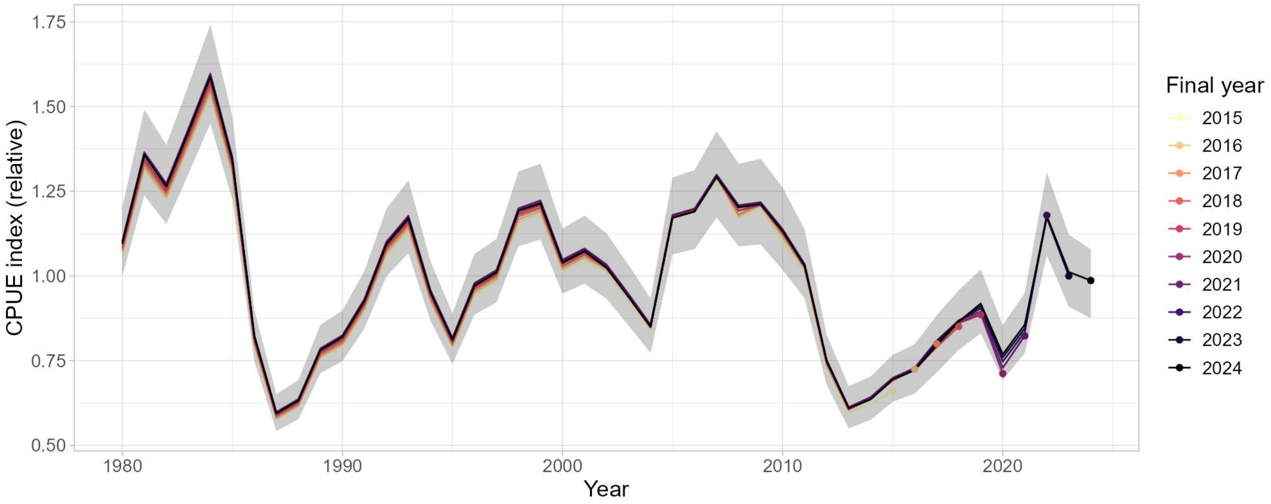

Figure 12: Retrospective analysis of the standardized CPUE index based on Norwegian data. The solid black line shows the index used in the current assessment, and colored lines retrospective indices with data restricted to January-October in the final year, peeling off years back to 2015. Index values are centered around the mean of the series. The shaded area marks the 95% confidence intervals. Indices were standardized using a GAMM implemented in glmmTMB.

7.2 - Model diagnostics

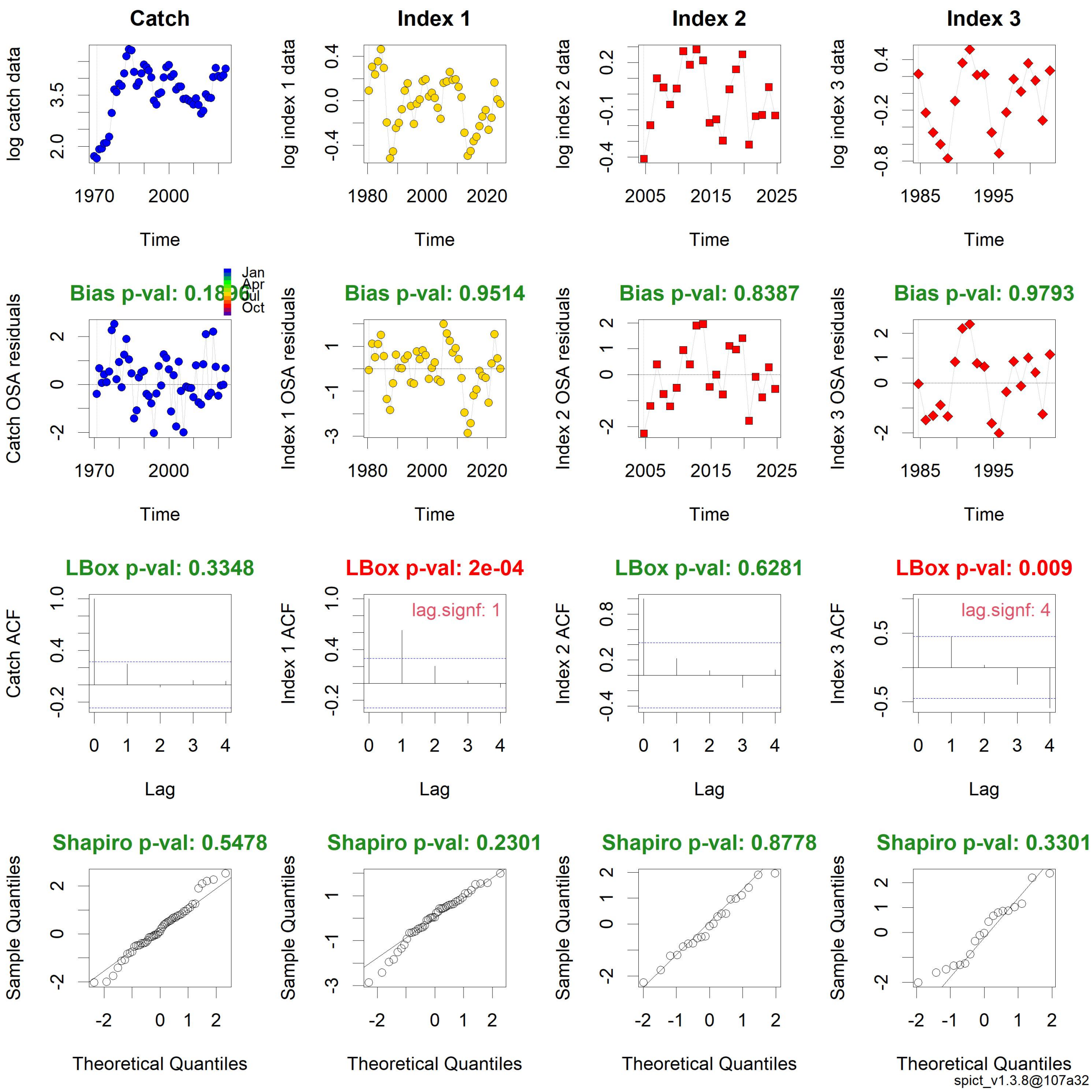

Figure 13: One-step-ahead residuals of the stock assessment model for the time series of catch, commercial CPUE (index 1), BESS (index 2) and historic surveys (index 3).

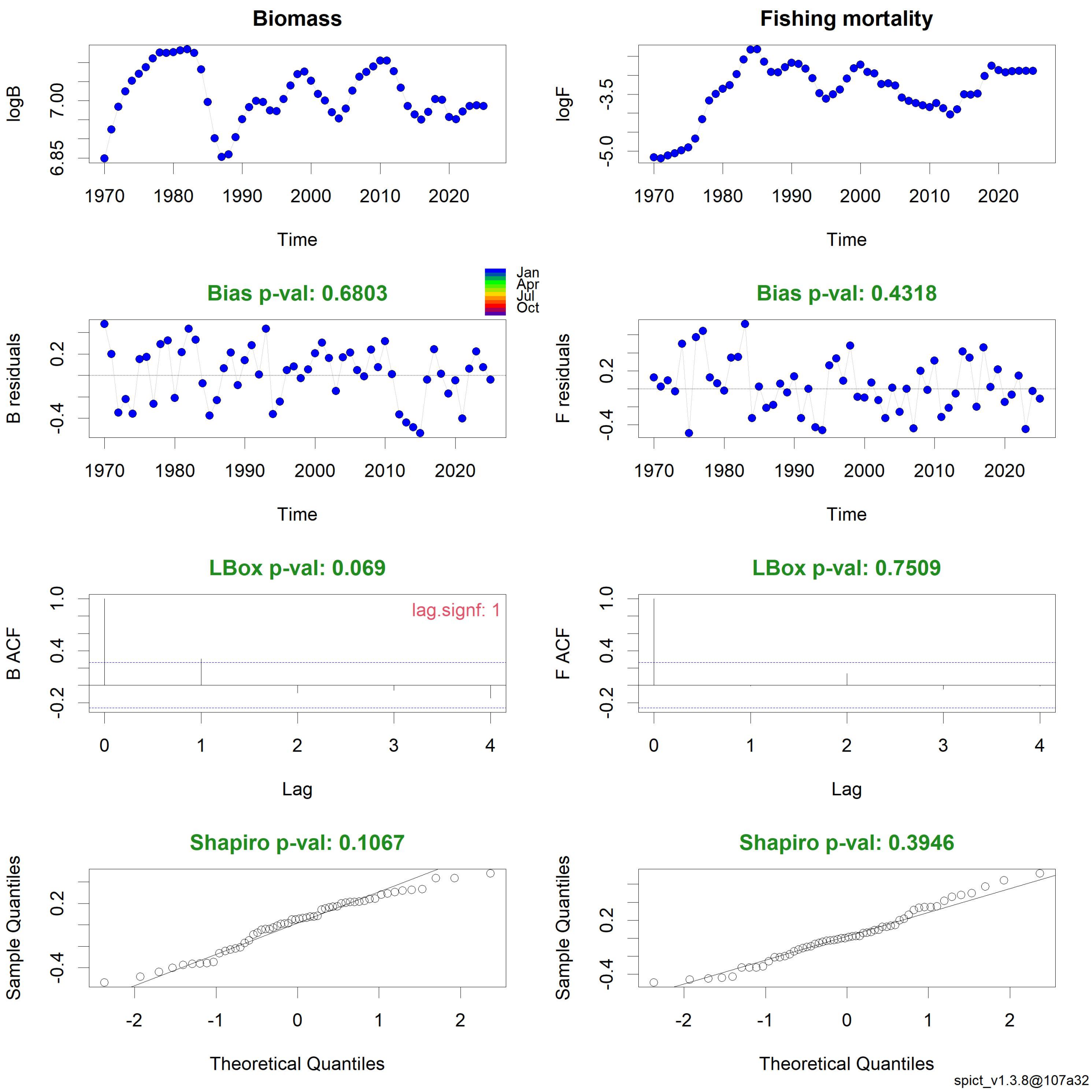

Figure 14: Residuals of the stock assessment model for the process errors of biomass and fishing mortality.

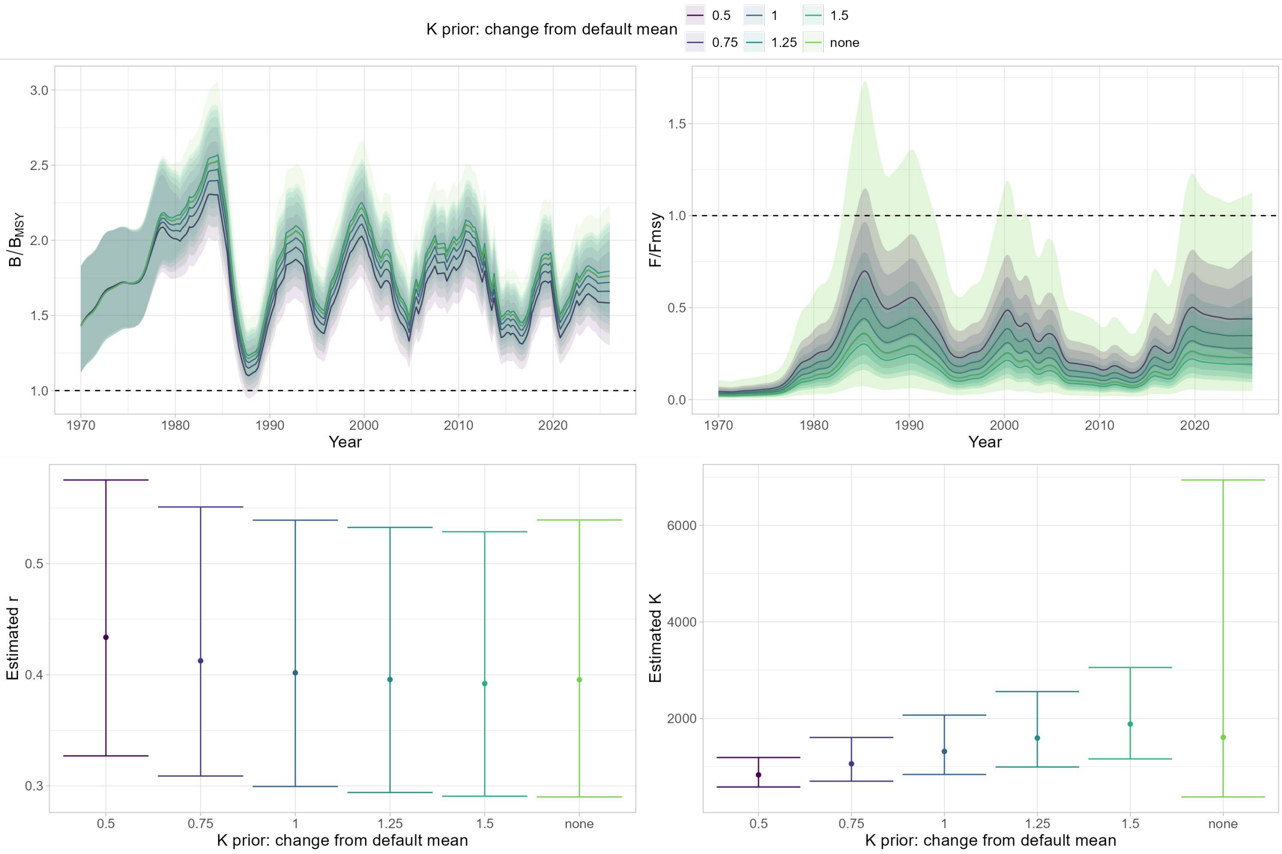

Figure 15: Sensitivity of model estimates of B/B_{MSY}, F/F_{MSY}, r and $_K$ to the mean of the K prior distribution. Included are model runs where K prior mean was varied between 50 and 150% of the final model configuration, as well as a model run without K prior ("none"). Shown are esti-mated means (lines/dots) and 95% confidence intervals (shaded areas/error bars).

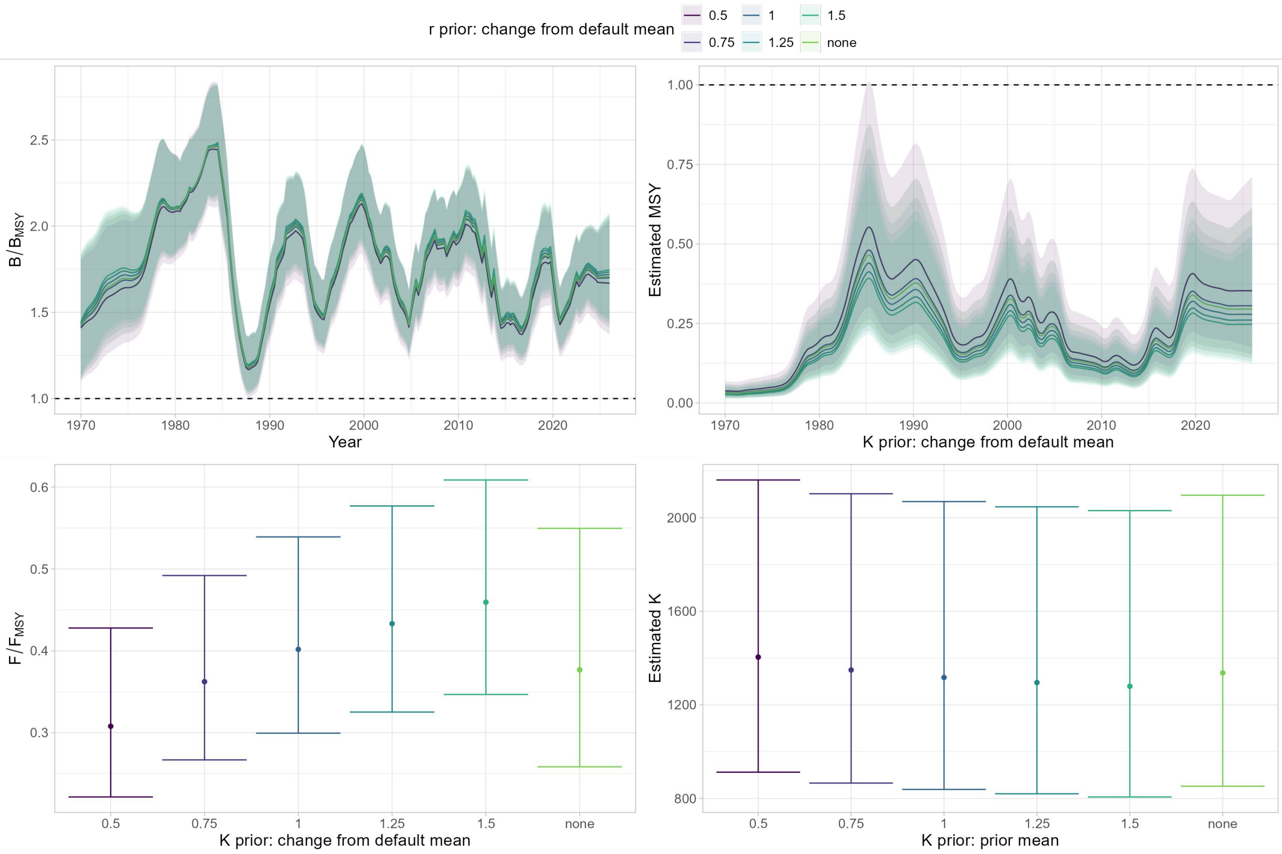

Figure 16: Sensitivity of model estimates of B/B_{MSY}, F/F_{MSY}, r and K to the mean of the r prior distribution. Included are model runs where r prior mean was varied between 50 and 150% of the final model configuration, as well as a model run without r prior ("none"). Shown are esti-mated means (lines/dots) and 95% confidence intervals (shaded areas/error bars).

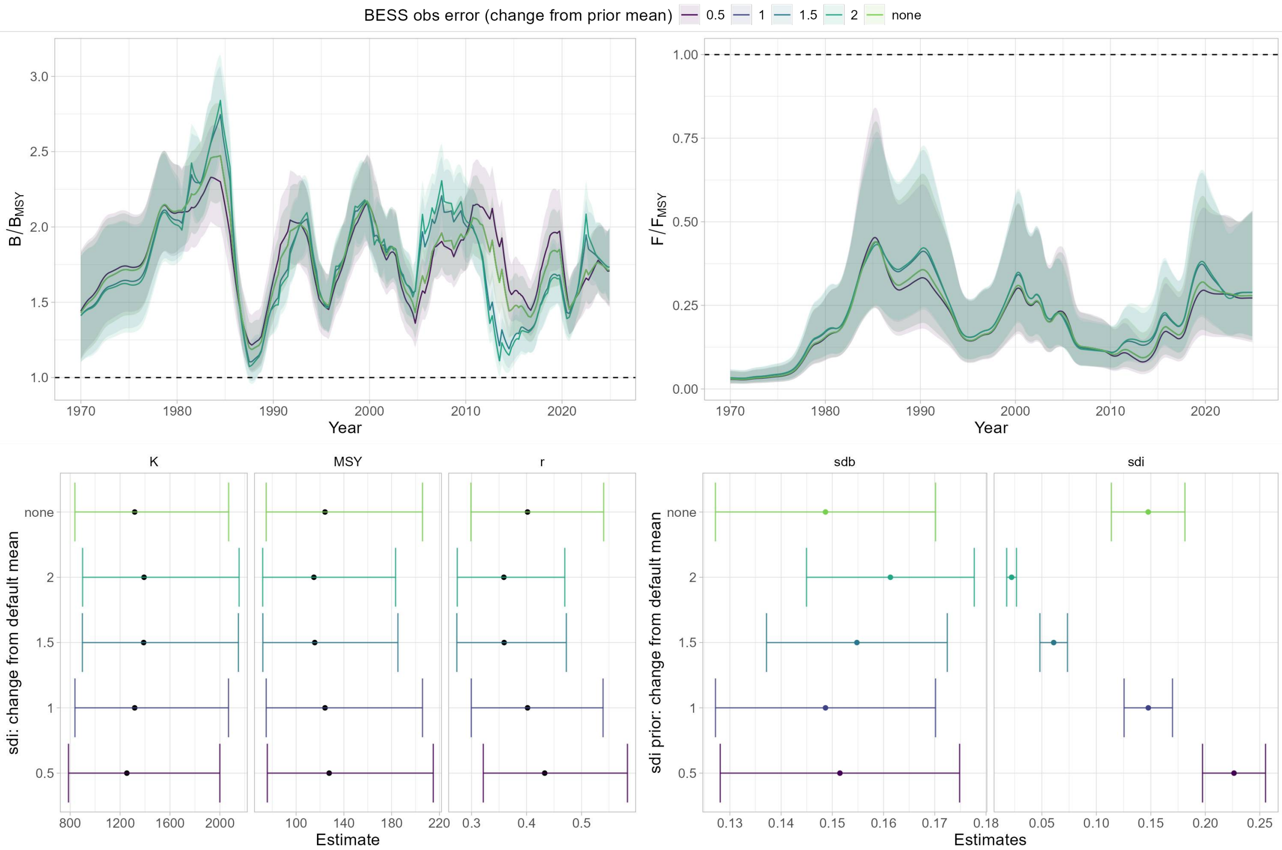

Figure 17: Sensitivity of model estimates of B/B_{MSY}, F/F_{MSY}, r, MSY and K, as well as biomass process error (sdb) and BESS index observation error (sdi) to the mean of the BESS sdi prior distribution. Included are model runs where BESS sdi prior mean was varied between 50 and 200% of the final model configuration, as well as a model run without a BESS sdi prior ("none"). Shown are estimated means (lines/dots) and 95% confidence intervals (shaded areas/error bars).

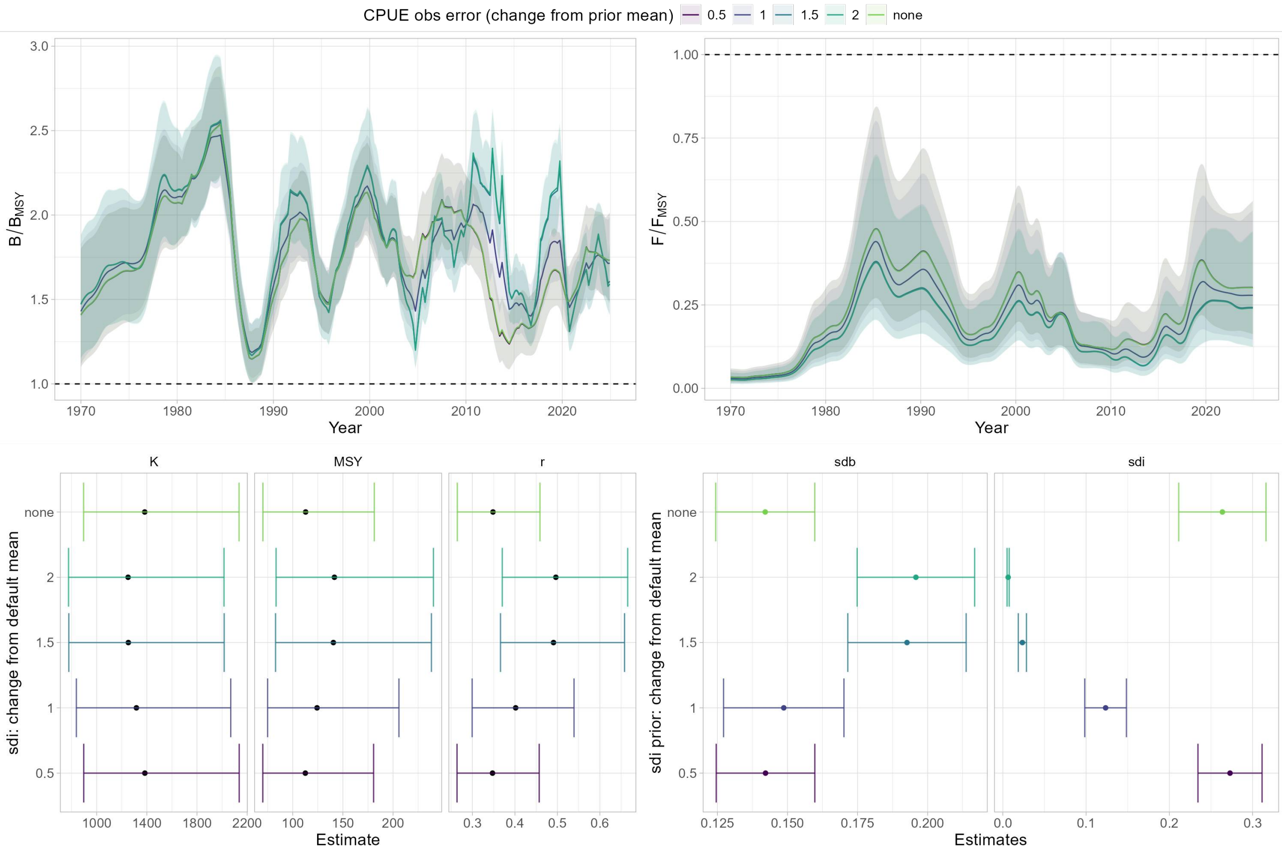

Figure 18: Sensitivity of model estimates of B/B_{MSY}, F/F_{MSY} , r, MSY and K, as well as biomass process error (sdb) and CPUE index observation error (sdi) to the mean of the CPUE sdi prior distribution. Included are model runs where CPUE sdi prior mean was varied between 50 and 200% of the final model configuration, as well as a model run without a CPUE sdi prior ("none"). Shown are estimated means (lines/dots) and 95% confidence intervals (shaded areas/error bars).

7.3 - Stock estimates

Table 7: Shrimp in the Barents Sea. Estimated exploitable biomass, catch and fishing mortality over time. Exploitable biomass og fishing mortality are relativ to B MSY and F MSY , with 95% confidence intervals (low and high values). Predicted catches are mean estimates of catches in the stock assessment model. Catch in the final year is based on preliminary information.

	Relative exploitable biomass					Relativ fishing mortality		
Year	B/B_{MSY} (low)	B/B_{MSY}	B/B_{MSY} (high)	Catch	Predicted catch	F/F_{MSY} (low)	F/F_{MSY}	F/F_{MSY} (high)
1970	0.88	1.43	2.32	6	5	0.01	0.03	0.09
1971	0.96	1.51	2.38	5	6	0.01	0.03	0.09
1972	1.04	1.60	2.46	7	6	0.01	0.03	0.10
1973	1.11	1.67	2.52	7	7	0.01	0.03	0.11
1974	1.15	1.71	2.53	8	8	0.01	0.04	0.11
1975	1.18	1.72	2.50	8	9	0.01	0.04	0.12
1976	1.20	1.72	2.47	10	11	0.02	0.05	0.15
1977	1.32	1.85	2.58	20	19	0.03	0.08	0.24
1978	1.51	2.07	2.83	39	33	0.04	0.12	0.37
1979	1.59	2.13	2.87	36	38	0.05	0.14	0.43
1980	1.61	2.11	2.75	46	43	0.05	0.16	0.49

	Relative exploitable biomass					Relativ fishing mortality		
Year	B/B (low)	B/B	B/B (high)	Catch	Predicted catch	F/F (low)	F/F	F/F (high)
1981	1.67	2.15	2.76	44	48	0.06	0.18	0.54
1982	1.73	2.23	2.86	63	65	0.07	0.23	0.69
1983	1.84	2.36	3.04	105	97	0.10	0.32	0.97
1984	1.90	2.46	3.20	128	121	0.13	0.40	1.25
1985	1.74	2.28	2.98	124	110	0.13	0.43	1.38
1986	1.32	1.74	2.28	65	69	0.11	0.36	1.17
1987	1.00	1.32	1.73	43	48	0.10	0.31	1.01
1988	0.91	1.20	1.57	49	49	0.10	0.32	1.01
1989	1.00	1.31	1.71	63	62	0.11	0.34	1.07
1990	1.21	1.58	2.07	81	74	0.11	0.35	1.10
1991	1.38	1.82	2.40	75	74	0.10	0.31	0.99
1992	1.51	1.98	2.61	69	67	0.08	0.27	0.85
1993	1.53	2.01	2.63	56	52	0.07	0.21	0.68
1994	1.38	1.80	2.35	28	33	0.05	0.16	0.50
1995	1.17	1.53	1.99	25	27	0.05	0.15	0.46
1996	1.18	1.54	2.01	35	33	0.05	0.16	0.50
1997	1.34	1.73	2.25	36	39	0.06	0.17	0.54
1998	1.50	1.94	2.52	56	55	0.07	0.22	0.67
1999	1.62	2.10	2.71	76	73	0.09	0.27	0.85
2000	1.65	2.14	2.78	81	77	0.10	0.30	0.94
2001	1.49	1.93	2.52	57	60	0.08	0.26	0.80
2002	1.41	1.84	2.40	61	58	0.08	0.25	0.79
2003	1.33	1.74	2.28	39	42	0.07	0.21	0.64
2004	1.18	1.55	2.03	43	41	0.07	0.22	0.69
2005	1.17	1.52	1.98	43	41	0.06	0.20	0.63
2006	1.30	1.68	2.16	30	31	0.04	0.14	0.43
2007	1.48	1.89	2.42	30	30	0.04	0.12	0.39
2008	1.49	1.90	2.44	28	28	0.04	0.12	0.37
2009	1.47	1.89	2.43	27	27	0.04	0.11	0.35
2010	1.52	1.94	2.49	25	26	0.03	0.10	0.32
2011	1.60	2.06	2.65	30	29	0.04	0.11	0.36
2012	1.51	1.96	2.54	25	25	0.03	0.10	0.33
2013	1.37	1.81	2.39	19	20	0.03	0.09	0.30
2014	1.22	1.61	2.13	21	22	0.04	0.12	0.37
2015	1.13	1.47	1.91	34	32	0.06	0.17	0.54
2016	1.13	1.46	1.89	31	31	0.06	0.17	0.54
2017	1.10	1.43	1.84	30	32	0.05	0.17	0.53
2018	1.28	1.66	2.15	56	55	0.08	0.25	0.77
2019	1.40	1.84	2.41	74	71	0.10	0.31	0.98

	Relative exploitable biomass					Relativ fishing mortality		
Year	B/B (low)	B/B	B/B (high)	Catch	Predicted catch	F/F (low)	F/F	F/F (high)
2020	1.33	1.73	2.26	58	59	0.10	0.30	0.95
2021	1.15	1.48	1.90	56	56	0.09	0.29	0.91
2022	1.24	1.60	2.06	60	61	0.09	0.29	0.91
2023	1.32	1.70	2.19	73	72	0.11	0.33	1.03
2024	1.37	1.77	2.29	83	82	0.12	0.37	1.19
2025	1.27	1.72	2.33					

7.4 - Audit

The stock assessment and advice were audited by Guldborg Søvik (IMR) and Yasaman Malekiyourtchi (IMR).

Institute of Marine Research – IMR

Polar branch of the FSBSI "VINRO" ("PINRO")