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An assessment of the Norwegian Deep/Skagerrak shrimp stock using the Stock Synthesis statistical framework

by

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Abstract

A length-based stock synthesis statisktical framework was applied to provide a quantitative assessment of the northern shrimp (*Pandalus boralis*) in Divisions IIIa and IV East (Skagerrak, Northern North Sea in the Norwegian Deep).

The model diagnostics of the assessment showed no major problems and were in line with the assessment of the benchmark 2016. The residuals of the proportion-at-length of the commercial fleet and survey were generally small with no apparent year or cohort effects. Model retrospective analyses showed that the SSB and R have been overestimated and F underestimated the last years.

Spawning stock biomass (SSB) decreased from a high level of 19780 tons in 2008 to the time series' low of 5800 t in 2014, then to increase slightly in 2015, but decrease again to 7100 tons in 2016. This is lower than MSY $B_{trigger}$ of 9900 tons, but greater than B_{lim} of 6300 tons. The stock has experienced a series of low recruitment years between 2008 and 2016, with the exeption of the high 2013 year class. Fishing mortality decreased from 0.94 in 2014, which was the highest value of the time series, to the second highest value of 0.78 in 2015. Consequently, the stock is currently exploited at a greater level than F_{msy} of 0.62.

Background

This stock was benchmarked in January 2016 (ICES 2016) when it was decided that a length based stock systhesis statistical framework should replace the surplus production model (Hvingel 2015) used since 2013, to assess status of the stock and form the basis for advice. Also reference points presented below were defined at the 2016 benchmark (ICES 2016).

Model description and configuration

A thorough description of the catch data, tuning index, biological information and a description of the stock synthesis model (SS3) and its configuration can be found in the stock annex produced during the benchmark 2016 (ICES 2016, for a link see the references section; see also the benchmark report (ICES 2016) for a model description and SCR Documents 16/53,56 and 57 for a description of the data used).

A summay of the data used in the model and the model settings can be found in Fig. 1 and Table 1, respecitvely. Whereas the assessment formally includes the 2016 year through estimated catches for this year and the survey index from the beginning of the year, the assessment results are interpreted as providing information on stock development up to January 1st 2016, i.e. not for the year 2016. Moreover, the survey does not provide information on the 2016 year class, for which abundance is unknown.

Model performance

Model convergence, log-likelihood values, number of parameters near bounds and estimates of the biological parameters for the final model are presented in Table 2. The modelled catches fitted well with the observed catches by quarter (Fig. 2). The predicted abundances similarly matched the observed survey indices, with the exeption of year 2016 (Figs. 3 – 5), due to a large decline in the survey index this year. The model estimates also fitted well to the observed length-compositions averaged over the time series, and when fitted on a yearly basis, for the commercial fleet and the surveys (Figs. 7 – 9). The residuals of the proportion-at-length of the commercial fleet and surveys were generally small, with no apparent year or cohort effects (Fig. 10). The model retrospective analyses of SSB, R and F show that the model overestimated the SSB and R the last three and five years respectively, and underestimated F the last two years (Figs. 14 – 16). The likely reason for this is that the large 2013 year class was unexpectedly not detected as a large number of 3 year old individuals in the survey 2016. The estimated fishery selectivity-at-length for the commercial fleet and for the surveys are shown in Fig. 6.

Sensitivity analysis

The benchmark in 2016 (ICES 2016) recognized the uncertainty in the current assumption of M = 0.75 to the assessment, which is based on estimates from the Barents Sea in the 1990s (Barenboim et al.1991), and recommended that the sensitivity of model outputs and catch advice to the specifications of M should be explored. Preliminary sensitivity analyses of the assessment model regarding different levels of M carried out at the current NIPAG meeting, showed that M = 0.90 does not change the perception of the current level of F and SSB relative to the reference points of F_{msy} and B_{pa} compared with M = 0.75 (base model; Fig. 17). Using M = 0.90, the SSB in 2017 will still be under B_{lim} (the new B_{lim}) at the current level of catches, indicating that the advice is rather robust to the assumption of M , within this range. However, shrimp in the North Sea/Skagerrak are considered to have a lifespan of only about half of that of shrimp in the Barents Sea and it is therefore likely that M could be substantially higher and outside the 0.75-0.90 range explored. Previous analyses of different M-assumptions for this stock (SCR 14/66) provide support for this hypothesis. NIPAG was not in a position at this meeting to fully explore the sensitivity to the M assumption used and stresses the importance of further investigations to be conducted no later than during the proposed benchmark in 2018-19.

Assessment results

The spawning stock biomass (SSB) has been variable over the assessment period 1988 to 2016 (Fig. 11). Since 2008, when SSB was 19780 tons, and which is the second highest SSB estimate/value of the time series, the stock decreased to the time series' low of 5800 tons in 2014. The stock then increased slightly in 2015, but decreased again to 7100 tons in 2016.

The recruitment (R) has, similarly to the SSB, been variable over the assessment period 1988 to 2015 (Fig. 12). A series of low recruitment years between 2008 and 2015, with the exception of year 2013, should be noted. During this period of low recruitment the estimates of SSB were also for some years historically low and below B_{lim} (Fig. 17). The uncertainties around the estimate of recruitment in 2015 is large. The reason for this is that the model has not yet seen the recruits in the fishery data (data until 2015), only in the survey data (January 2016).

Fishing mortality (F) for ages 1 to 3 remained relatively stable since the beginning of the 1990s to about 2010 (Fig. 13). After 2010, F increased steeply to 0.94 in 2014, which is the highest value of the time series, to the second highest value of 0.78 in 2015. The stock is consequently exploited at a greater level than the F_{msy} of 0.62. (Fig. 17).

A summary of the reference points determined at the benchmark (ICES 2016) is presented in Table 3.

Quality of the assessment

The benchmark that took place in January 2016 (ICES 2016) agreed on a quarterly length-based model as the basis for the assessment and the provision of catch advice for this *Pandalus* stock. The length-based model is considered preferable to the previous surplus production model because it makes more use of the available data, including using observed lengths and a quarterly time step to achieve a better representation of the population structure and dynamics. The length-based model is able to better take into account year-to-year changes in recruitment and how these changes influence catch options in the short term.

Input data are considered to be of good quality. However, the survey time series has not been standardised for variability in factors such as swept volume, spatial coverage and trawling speed, which might add uncertainty to the stock estimates. Moreover, the survey indicated a large decline in biomass in 2016, which is not observed in the lpue of the Swedish, Norwegian and Danish fleets.

The assessment and the derived advice depend on the assumption of natural mortality. However, exploration conducted during the benchmark suggests that *M* might be larger than assumed in the current model.

B_{lim} was set to B_{loss}, however, recruitment estimates suggest that large year classes could be produced at levels of *SSB* close to B_{loss} and therefore B_{lim} might be overestimated. The values below B_{lim} in the 2016 assessment is due to the SSB curve being shifted slightly downwards compared to in the benchmark assessment, and that the reference points are not updated

Discarding practices in the Norwegian fishery are unknown, and Norwegian discards have been estimated by applying the Danish discard ratio to Norwegian data.

Catch options

The basis for the catch options are as follows:

Variable	Value	Source	Notes
F_{2016}	1.53	ICES (2016)	Corresponds to the assumed catch in 2016.
SSB_{2016}	7077 t	ICES (2016)	
R_{2016}	6838538 thousands	ICES (2016)	GM 2006–2015
Catch (2016)*	12842 t	ICES (2016)	Equal to projected landings 2016 plus estimated discards.
Landings (2016)**	11085 t	ICES (2016)	Projected landings 2016
Discards (2016)	1757 t	ICES (2016)	Average discard rate in 2013–2015 (12.5%)

* Equal to projected landings corrected for weight loss due to on-board boiling, and with estimated discards added.

** Swedish projected landings 2016 are recorded landings corrected by applying a factor of 1.13 to boiled landings to correct for weight loss due to on-board boiling. Danish and Norwegian projected landings 2016 are not corrected for boiling.

The catch options as presented in the ICES advice are as follows:

Rationale	Catch (2017)	Wanted catch* (2017)	Basis	F catch (2017)	SSB (2018)	%SSB change^	%TAC change^^
MSY approach	2840	2485	B_{lim} in 2018	0.30	6310	129	-84
Zero catch	0	0	F = 0	0	8054	192	-100
Other options	5146	4503	F_{MSY}	0.62	4991	81	-71
	1725	1509	$F = F_{MSY} \times (SSB_{2017}/ \text{MSY } B_{trigger})$	0.17	6981	153	-90
	9406	8230	F_{2016}	1.53	2875	4	-48

* "Wanted catch" is used to describe shrimp that would be landed in the absence of the EU landing obligation, and has been calculated based on the average discard rates in 2013–2015 (12.5%).

^ SSB 2018 relative to SSB 2017.

^^ Wanted catch 2017 relative to TAC 2016.

An extended set of catch options can be found in Annex 1.

At the benchmark in January 2016, a new assessment method and new reference points were agreed. The new assessment model is better able to capture year-to-year changes in stock abundance, in particular in connection with the variable recruitment, and this had substantial impact on the resulting short-term forecast for 2016, which was revised in March 2016.

While there are some differences in assessment results in the present advice compared with the advice issued in October 2015 (i.e. when the production model was used for the assessment) the development of the stock over time as estimated by the current assessment is rather similar to that derived from the production model. The main difference lies in the re-calculation of the reference points, which has resulted in a change in the perception of stock status relative to these reference points.

The 2016 assessment conducted during the benchmark indicated that the stock was below *MSY* $B_{trigger}$ in 2015 and was projected to be above *MSY* $B_{trigger}$ in 2016. The current advice indicates that fishing mortality in 2015 and 2016 is much larger than F_{MSY} and that the biomass is below *MSY* $B_{trigger}$. This change in the perception of the stock status is caused by the downward revision of the 2013 year class in the 2016 survey and in the current assessment.

Due to the current low level of the *SSB*, and the fact that the fishery is dependent on the incoming year class, in combination with the uncertainty in the magnitude of the decline of the survey estimate between 2015 and 2016, ICES consider that the assessment and the advice should be updated in the beginning of the 2017 after the results of the 2017 survey will be available.

References

Hvingel, C. 2015. The 2015 assessment of the North Sea/Skagerrack shrimp stock using a Bayesian surplus production model. NAFO SCR Doc. 15/059. Serial No. N6495.

ICES. 2016. Report of the Benchmark Workshop on *Pandalus borealis* in Skagerrak and Norwegian Deep Sea (WKPAND), 20–22 January 2016, Bergen, Norway. ICES CM 2016/ACOM:39. 20 pp.

ICES 2016 Stock annex:

The stock annes is available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular Stock Annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species,* and *acronym* of the relevant ICES expert group.

STOCK ID	STOCK NAME	LAST UPDATED	LINK
pand_SA	*Pandalus* in Skagerrak and Norwegian Deep (ICES Division IIIa and IVa East)	January 2016	*Pandalus*

Table 1. Settings and results of the final SS3 assessment model. The table columns show: number of estimated parameters, the initial values (from which the numerical optimization is started), the intervals allowed for the parameters, and the value estimated by maximum likelihood. Parameters in bold were set and not estimated by the model. No priors were used on any parameter.

PARAMETER	NUMBER ESTIMATED	INITIAL VALUE	BOUNDS (LOW,HIGH)	VALUE (MLE)
Natural mortality				
M		0.75		
Stock and recruitment				
Ln(R0)	1	6	(3,30)	16.19
Steepness (h)		0.99		
Recruitment variability (σR)		0.60		
Ln (Recruitment deviation): 1981–2014	35			
Recruitment autocorrelation		0		
Growth				
Linf (cm)	1	2.9	(2,4)	2.82
k	1	0.39	(0.20–0.50)	0.43
L at minimum age (0.001 years) t0	1	0	(0,4)	0.06
CV of young individuals	1	0.20	(0.005–0.40)	0.13
CV of old individuals	1	0.05	(0.005–0.40)	0.03
Weight-(kg) at-length (cm)				
A		0.0016		
B		2.7532		
Maturity				
Length (cm) at 50% mature		1.8		
Length (cm) at 95% mature		1.9		
Initial fishing mortality				
Commercial trawl fleet	1	0.1	(0,4)	2,12
Catchability and selectivity (logistic)				
Commercial trawl fleet				
Time-invariant length-based logistic selectivity	2 the parameters are L50%sel and L95%sel-L50%sel (in cm)	1,1	(0,4.5)	(1.63,0.35)
Norway survey (1988–2002)				
Ln(Q) – catchability	1	-	(0,1)	0.003

Parameter	Number estimated	Initial value	Bounds (low,high)	Value (MLE)
Extra variability added to input standard deviation	1	0	(0,1)	0.13
Time-invariant length-based logistic selectivity	2 the parameters are L50%sel and L95%sel-L50%sel (in cm)	1,1	(0,4.5) for both parameters	(1.93,0.80)
Norway survey (2004–2005)				
Ln(Q) – catchability	1	-	(0,1)	0.003
Extra variability added to input standard deviation	1	0		
Time-invariant length-based logistic selectivity	2 the parameters are L50%sel and L95%sel-L50%sel (in cm)	1,1	(0,4.5) for both parameters	(1.45,0.35)
Norway survey (2006–2015)				
Ln(Q) – catchability	1	-	(0,1)	0.001
Extra variability added to input standard deviation	1	0	(0,1)	0.16
Time-invariant length-based logistic selectivity	2 the parameters are L50%sel and L95%sel-L50%sel (in cm)	1,1	(0,4.5) for both parameters	(1.49,0.58)

Table 2. Results of the SS3 assessment model. Model convergence, total log-likelihood (MLE), length-frequency distributions log-likelihood (LFD), survey index log-likelihood (CPUE), recruitment deviations log-likelihood (Recr dev) and number of parameters near bounds.

CONVERGENCE	TOTAL	LENGHT COMP	SURVEY CPUE	REC DEV	PARA NEAR BOUNDS
0,0002205	**149,797**	**176,966**	**-17,8948**	**-9,34842**	**0**

Table 3. SS3 final model with quarterly time-step. Summary of the assessment.

YEAR	REC (AGE 0) THOUSANDS	B TOTAL JANUARY 1 (TON)	SSB JANUARY 1 (TON)	CATCH (TON)	F (1-2.5 CM)	F (1-3 YEARS)
1988	8618650	24992	13077	12177	0.54	0.62
1989	12223600	20946	8695	11249	0.68	0.77
1990	12798300	24197	7044	10239	0.52	0.58
1991	9209620	31508	10302	11595	0.41	0.46
1992	17021300	33754	14588	13081	0.4	0.45
1993	8893240	37616	14891	12753	0.38	0.43
1994	10458200	39699	17168	11549	0.28	0.31
1995	13496900	37849	20342	13361	0.36	0.41
1996	14689900	37245	16461	14149	0.42	0.47
1997	7449280	40171	15918	15074	0.41	0.46
1998	9909750	37099	17824	15504	0.43	0.49
1999	9339180	30527	15383	11254	0.39	0.44
2000	9054270	29610	12996	11038	0.39	0.44
2001	16221700	28986	12994	11328	0.42	0.47
2002	10445000	34114	12375	12474	0.41	0.47
2003	13507200	38008	15177	13836	0.37	0.42
2004	9283370	38695	17629	15952	0.46	0.51
2005	16878400	35382	15829	14208	0.42	0.47
2006	11806300	37741	15079	14268	0.44	0.49
2007	11221900	40910	16289	13552	0.33	0.38
2008	5098770	40212	19776	13554	0.34	0.38
2009	4547680	32865	18389	11539	0.34	0.38
2010	4930500	23364	14638	8327	0.35	0.4
2011	7814620	18023	9719	9044	0.58	0.67
2012	5618690	16597	5941	8822	0.68	0.77
2013	12720600	16683	5813	9288	0.68	0.76
2014	5204940	21058	5758	12341	0.84	0.94
2015	5079720	20991	7171	12162	0.69	0.78
2016	NA	NA	7077	NA	NA	NA

Table 4. Summary of the reference points determined at the benchmark in 2016 (ICES 2016).

	Type	Value	Technical basis
MSY Approach	MSY $B_{trigger}$	9900 t	5th percentile of equilibrium distribution of SSB when fishing at F_{MSY}, constrained to be no less than B_{pa}
	F_{MSY}	0.62	F that maximises median equilibrium yield (defining yield as the total catch)
Precautionary Approach	B_{lim}	6300 t	B_{loss} (lowest observed SSB)
	B_{pa}	9900 t	B_{lim} * exp(1.645 * σ), where σ = 0.27
	F_{lim}	1.00	F that leads to 50% probability of SSB < B_{lim}
	F_{pa}	0.68	F_{lim} * exp(- 1.645 * σ), where σ = 0.23

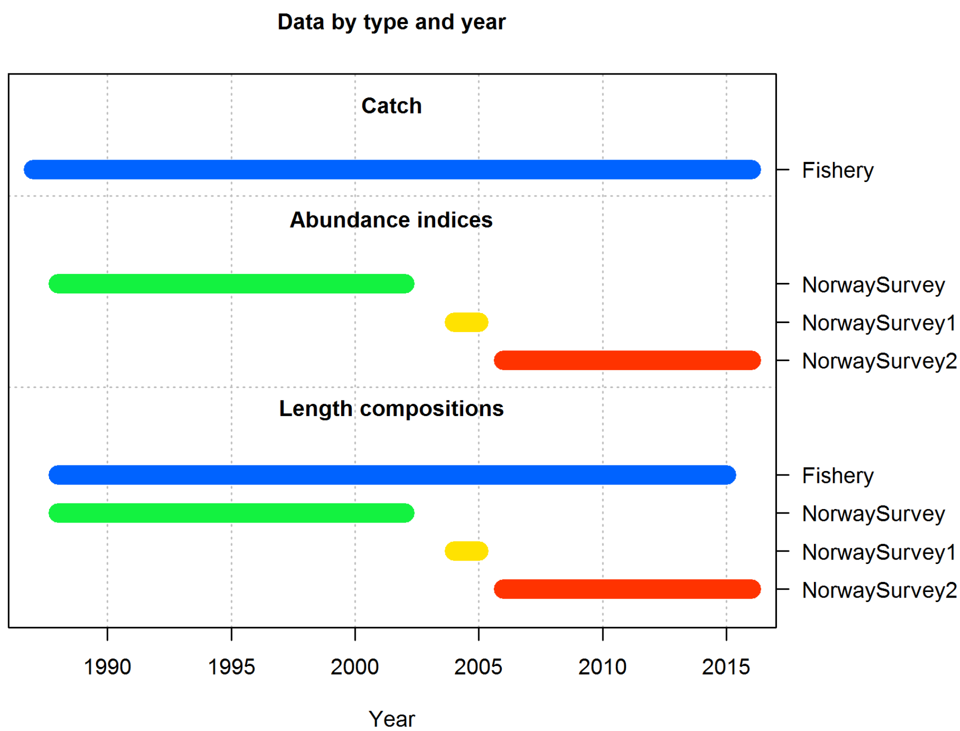

Fig. 1. Data by type and year for each fleet and survey used in the SS3 model of the northern shrimp in the northern part of ICES Division IIIa (Skagerrak) and the eastern part of Division IVa (Norwegian Deep).

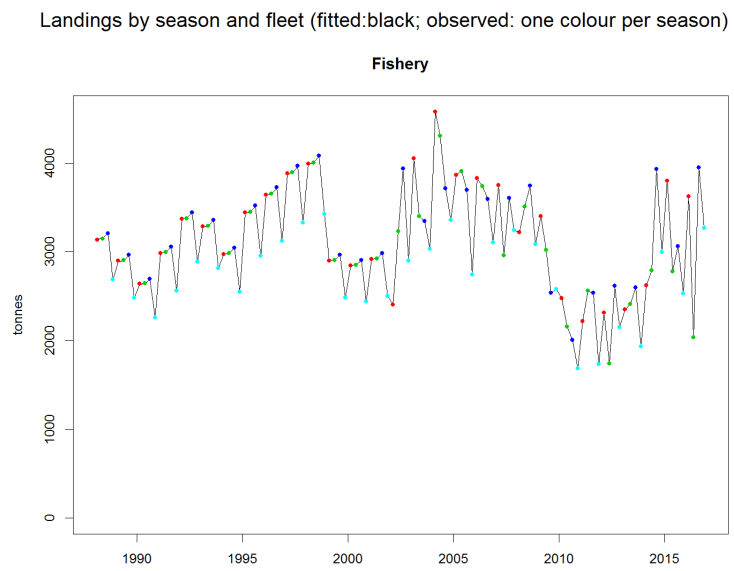

Fig. 2. Observed and fitted catches (in tons) in the SS3 final model by quarter. Observed data are colour coded as follows: Quarter 1: red, Quarter 2: green, Quarter 3: blue, Quarter 4: sky blue.

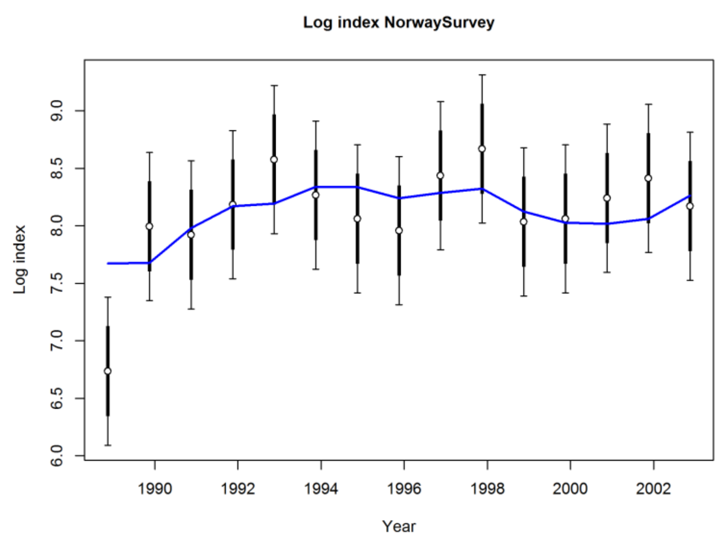

Fig. 3. Predicted abundances (blue line) and observed survey index (dots) with estimated 95% probability intervals of the survey index (first survey period).

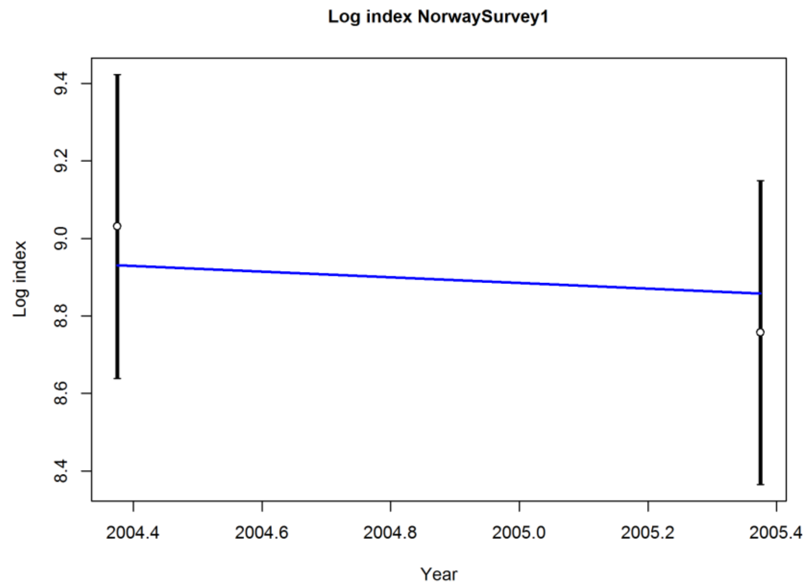

Fig. 4. Predicted abundances (blue line) and observed survey index (dots) with estimated 95% probability intervals of the survey index (second survey period).

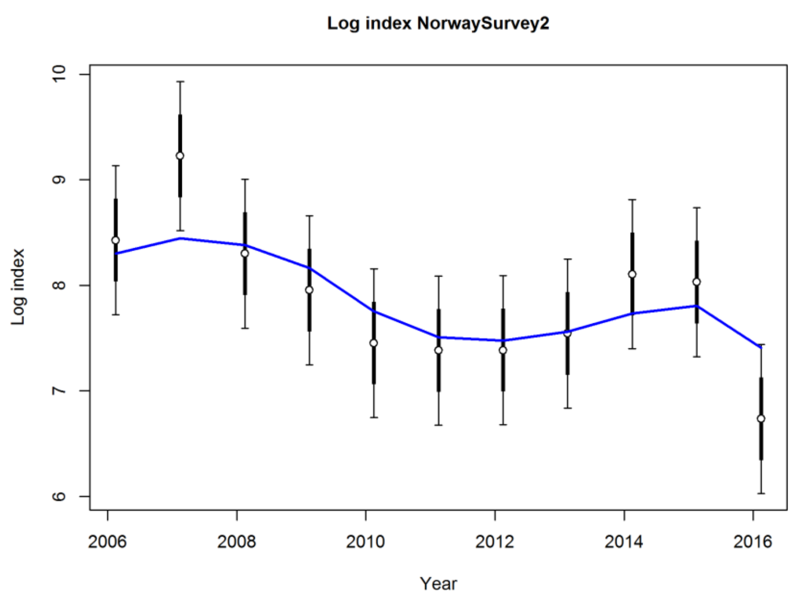

Fig. 5. Predicted abundances (blue line) and observed survey index (dots) with estimated 95% probability intervals of the survey index (third survey period).

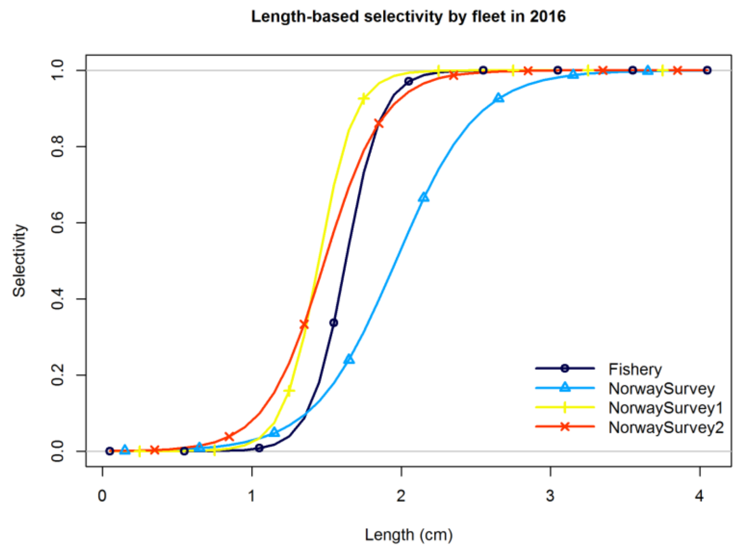

Fig. 6. Fishery selectivity-at-length estimated for the commercial fleet and for the surveys in the SS3 model.

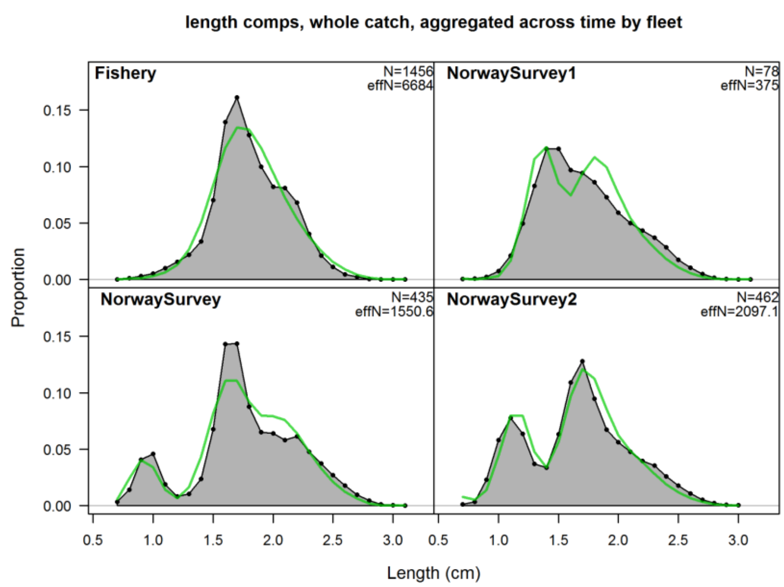

Fig. 7. Average model fits to the length-composition data estimated for the commercial fleet and for the surveys (shown as observed and predicted length-frequency distributions, averaged across of all data years) for the SS3 model.

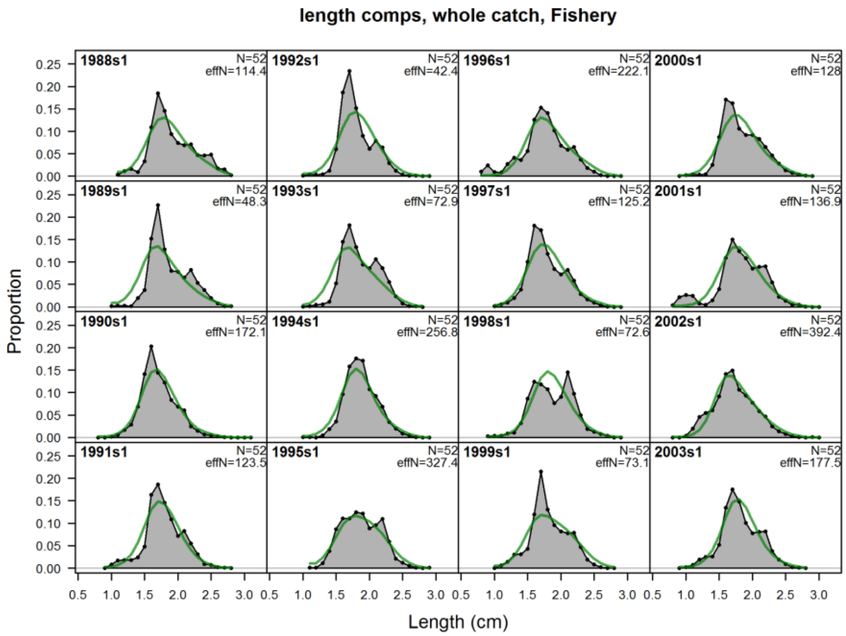

Fig. 8a. Yearly model fits to the length-composition data estimated for the commercial fleet (shown as observed and predicted length-frequency distributions by year) for the SS3 model.

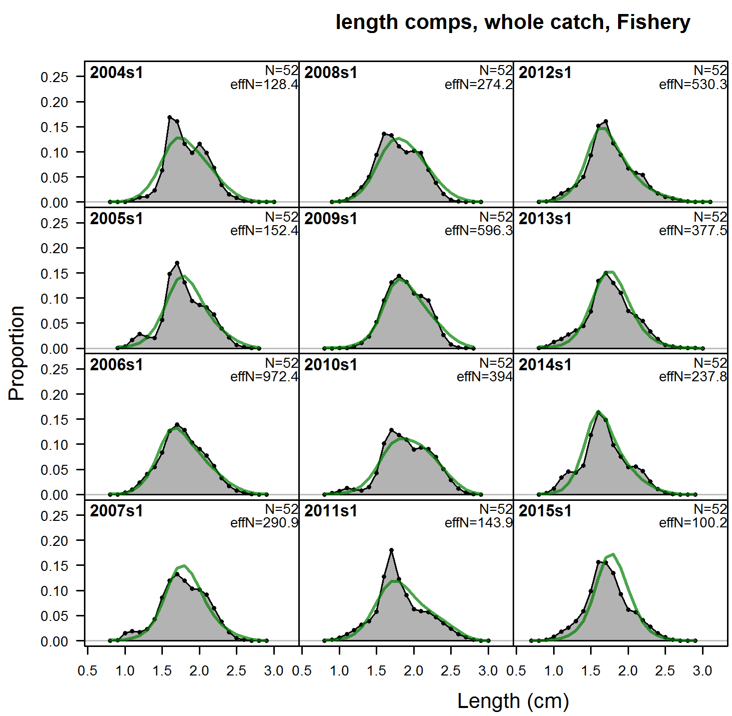

Fig. 8b. Yearly model fits to the length-composition data estimated for the commercial fleet (shown as observed and predicted length-frequency distributions by year) for the SS3 model.

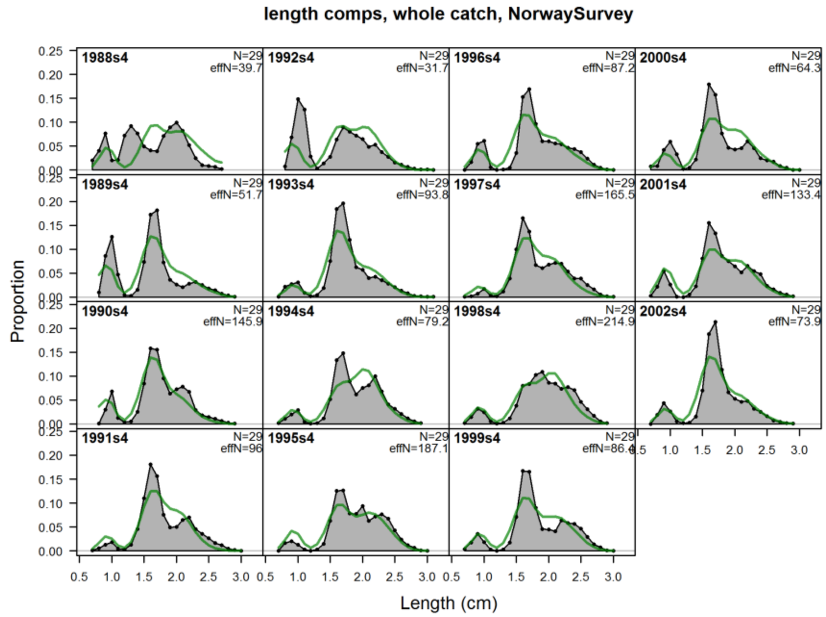

Fig. 9a. Yearly model fits to the length-composition data estimated for the first survey period (shown as observed and predicted length-frequency distributions by year) for the SS3 final model.

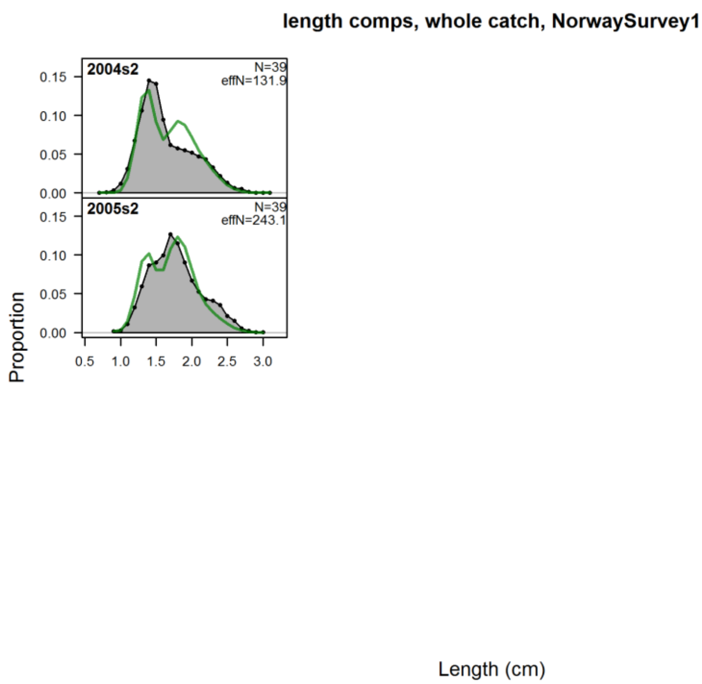

Fig. 9b. Yearly model fits to the length-composition dada estimated for the second survey period (shown as observed and predicted length-frequency distributions by year) for the SS3 final model.

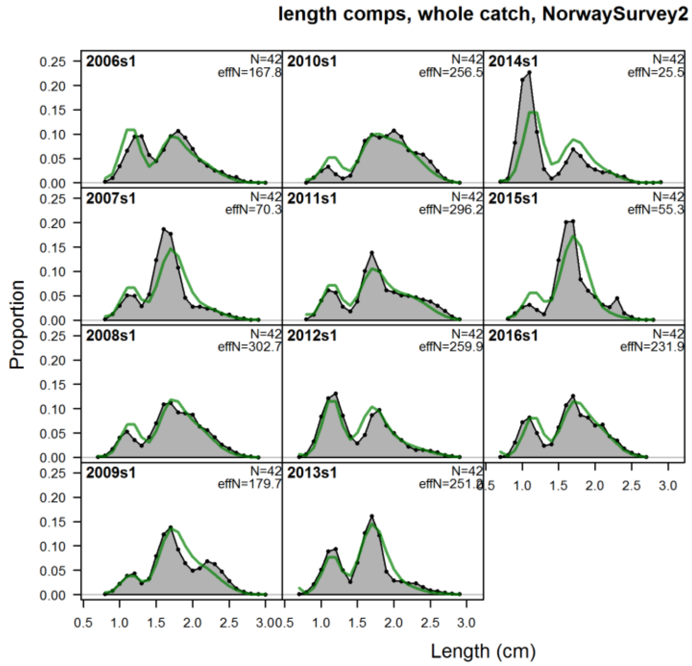

Fig. 9c. Yearly model fits to the length-composition dada estimated for the third survey period (shown as observed and predicted length-frequency distributions by year) for the SS3 final model.

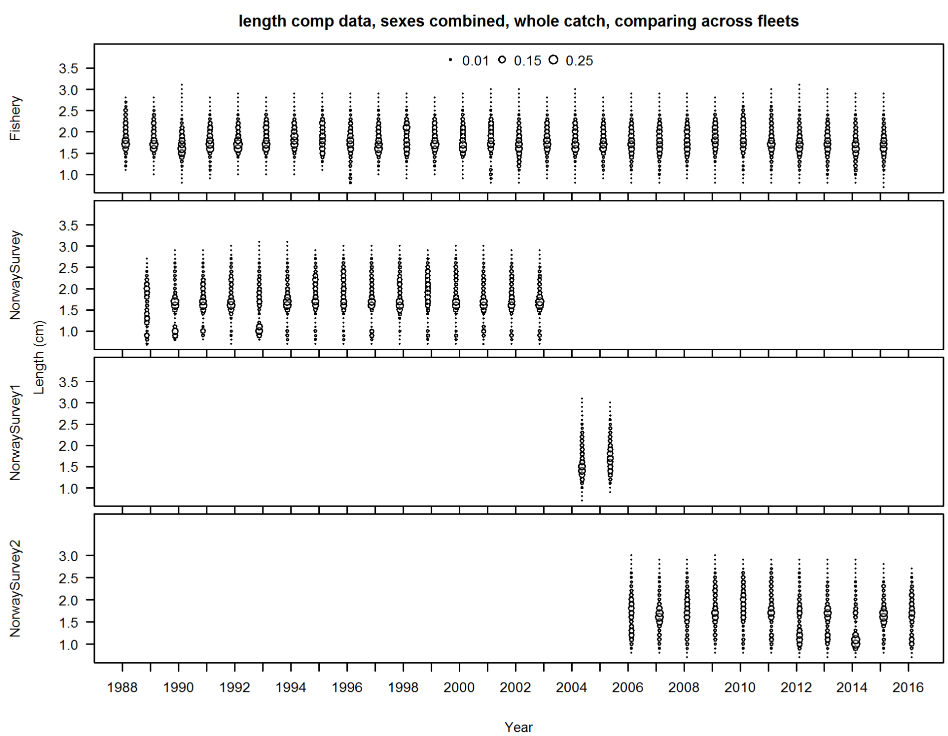

Fig. 10. Pearson residuals for the proportions-at-length in the commercial fleet and surveys of the SS3 final model.

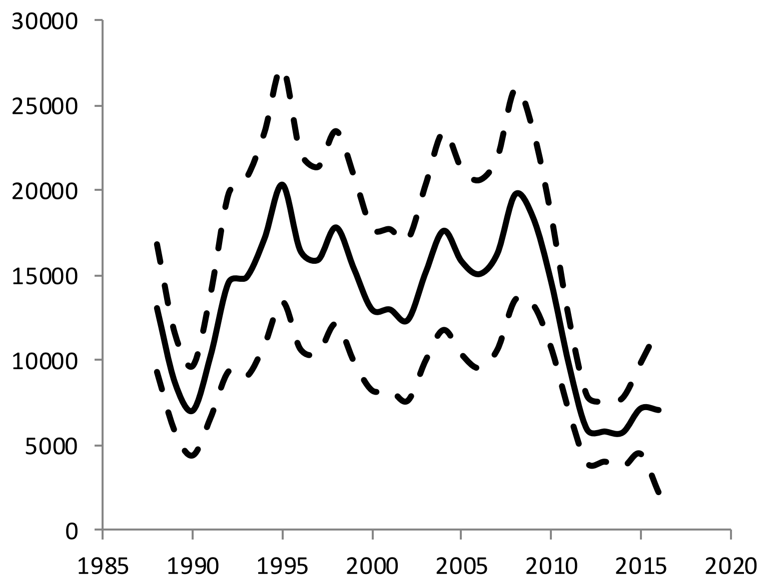

Fig. 11. Time trajectories of spawning biomass (January 1st) +/- 1 standard deviation of the estimates as estimated by the model.

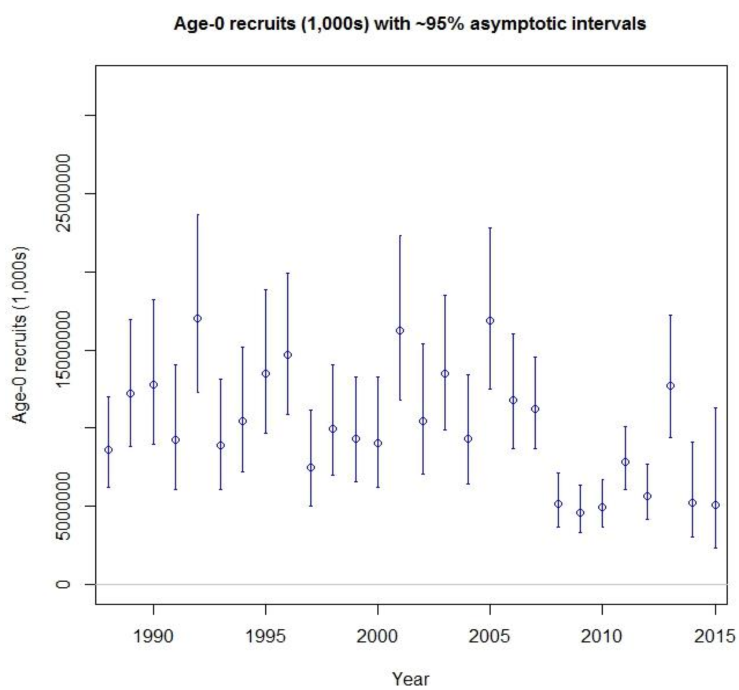

Fig. 12. Time trajectories of (age 0) recruitment (January 1st) +/- 1 standard deviation of the estimates as estimated by the model.

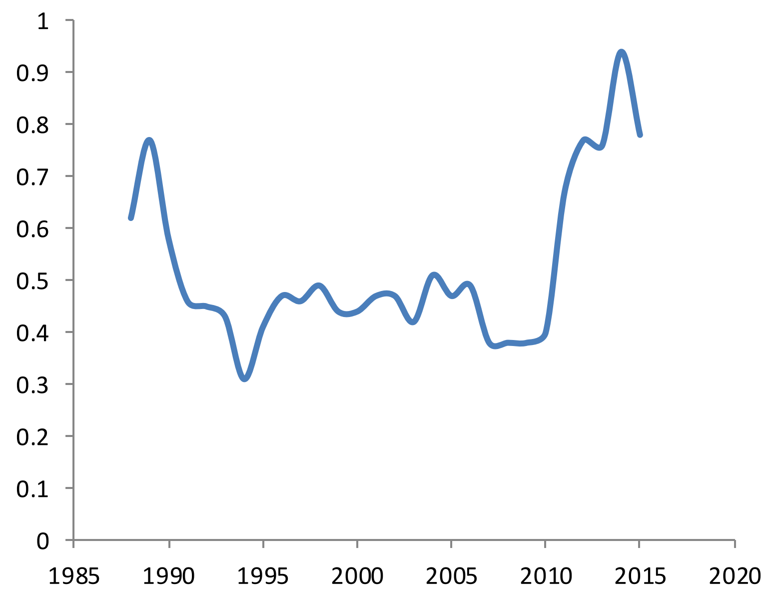

Fig. 13. Time trajectories of fishing mortality (ages 1-3) estimated by the model.

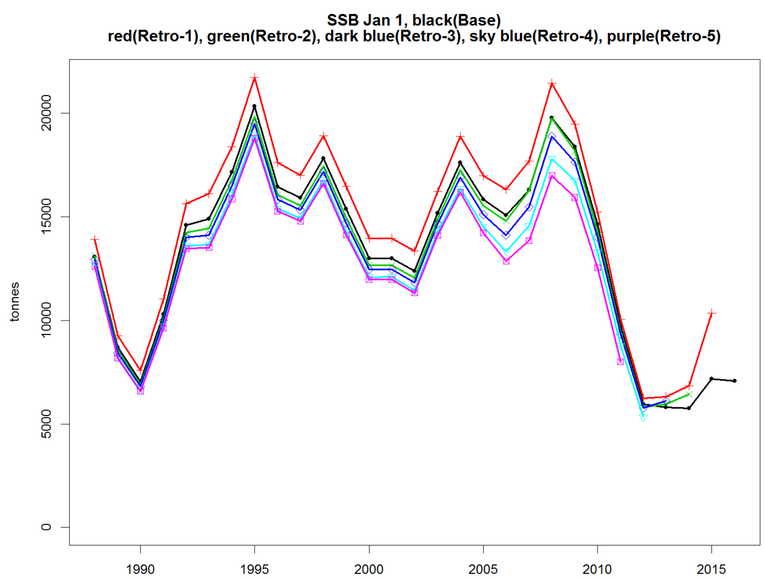

Fig. 14. Retrospective analysis of the SS3 model: SSB (January 1).

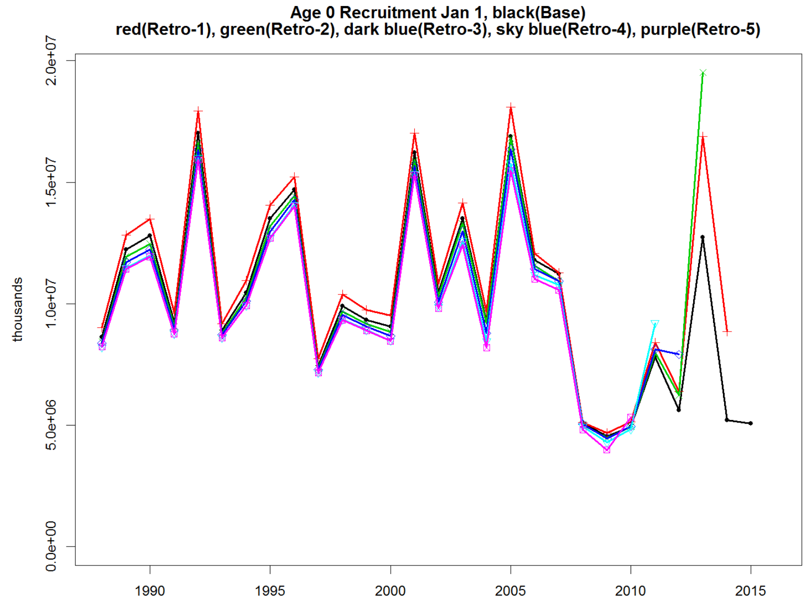

Fig. 15. Retrospective analysis of the SS3 model: Recruitment (age 0 abundance on January 1).

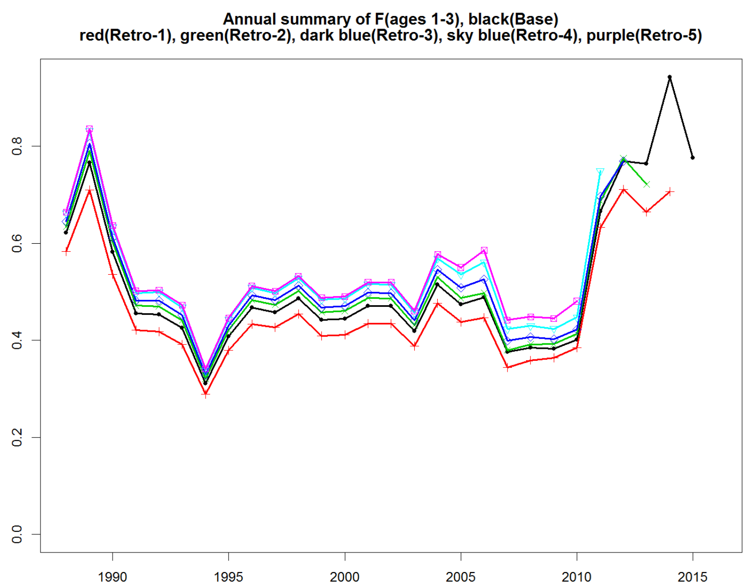

Fig. 16. Retrospective analysis of the SS3 model: F(ages 1-3).

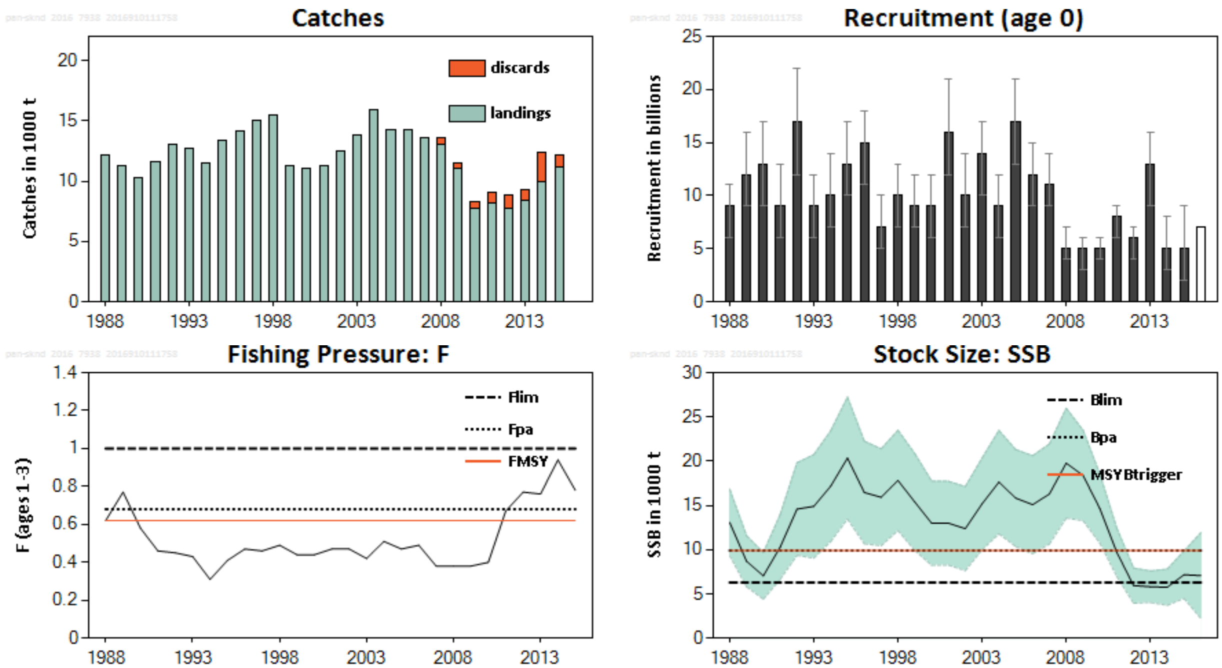

Fig 17. Summary assessment output: Total catch, including estimated discards since 2008 (tons) and F, SSB and R assessment results. SSB and R depicted with 90% confidence intervals. The assumed recruitment value for 2016 is unshaded.

Fig. 18. Northern shrimp in Skagerrak and Norwegian Deep: *F* and *SSB* assessment results for natural mortality M = 0.75 (base model, black) and M = 0.90 (red). Straight lines indicate B_{pa} (left figure panel) and F_{msy} (right figure panel) based on the different runs.

Annex 1.

SSB (2016)	Rec proj	F (1-2.5cm)	F (1-3years)	Catch (2016)	Land (2016)	SSB (2017)
7077	6838538	1.36	1.53	12842	11085	2755

Fmult	Fcatch (1-2.5cm)	Fland (1-2.5cm)	Fdisc (1-2.5cm)	Fcatch (1-3years)	Catch (2017)	Land (2017)	Disc (2017)	SSB (2018)
0	0	0	0	0	0	0	0	8054
0.1	0.0733	0.0733	0	0.0827	855	715	140	7517
0.2	0.1467	0.1467	0	0.1654	1648	1373	276	7027
0.3	0.22	0.22	0	0.2481	2387	1979	408	6580
0.4	0.2934	0.2934	0	0.3308	3075	2537	538	6171
0.5	0.3667	0.3667	0	0.4135	3717	3052	665	5796
0.6	0.44	0.44	0	0.4962	4317	3529	788	5453
0.7	0.5134	0.5134	0	0.5789	4879	3970	909	5138
0.8	0.5867	0.5867	0	0.6616	5405	4378	1027	4849
0.9	0.66	0.66	0	0.7443	5899	4757	1142	4583
1	0.7334	0.7334	0	0.827	6363	5108	1255	4338
1.1	0.8067	0.8067	0	0.9097	6801	5435	1365	4113
1.2	0.8801	0.8801	0	0.9924	7213	5740	1473	3904
1.3	0.9534	0.9534	0	1.0751	7602	6024	1579	3711
1.4	1.0267	1.0267	0	1.1578	7971	6289	1682	3533
1.5	1.1001	1.1001	0	1.2406	8319	6536	1783	3368
1.6	1.1734	1.1734	0	1.3233	8650	6768	1882	3214
1.7	1.2467	1.2467	0	1.406	8964	6985	1979	3071
1.8	1.3201	1.3201	0	1.4887	9263	7188	2074	2938
2	1.4668	1.4668	0	1.6541	9818	7559	2259	2698