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Improvement of the Greenland shrimp model

by

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Abstract

In 2017 NAFO Scientific Council asked for an exploration of the apparent instability of the Greenland shrimp model. A small group of shrimp scientists met to further explore and evaluate the model. They concluded that mainly two model changes lead to significant improvements of model stability. Firstly changing the thirty-year time window of input data to cover the full length of available data will remove the problems of losing important data for especially the cod-shrimp interaction. Secondly changing from a time invariant catchability parameter of the commercial fleet to a time-variable catchability improved the stability of the model. In addition, model priors were visited and changed if necessary. The model changes led to a more robust model, which is recommended to be applied in the 2018 shrimp assessment.

Introduction

The West Greenland shrimp stock has since 2002 been assessed by a biomass-production model including an explicit term for cod prediction (Hvingel and Kingsley 2005). Within a Bayesian framework the population dynamic is fitted to series of CPUE, catch, and survey biomass indices. Since its introduction, this assessment model has undergone a suite of modifications (Kingsley 2015).

In 2017 NAFO Scientific Council said: *SC is concerned that the 2017 parameter estimate of MSY was quite different than that estimated in 2016 suggesting some degree of instability of the model. This was further demonstrated by changes in perception of stock trajectory in recent years based on a 5-year retrospective analysis. The assessment model may not fully reflect the uncertainty associated with stock status.* And, NIPAG recommended *that the instability of the model should be explored*.

The model instability noted by NIPAG and SC in 2017 is best summarized in the 5-years retrospective plot (Fig. 1).

First, there is parallel shift in the models estimates of the relative biomass between assessments year. These shifts are gradually downward from 2013 to 2016 giving a sequential more pessimistic perception of the stock; however, this trend ends in the 2017 assessment when the trajectory is shifted back up (Fig. 1).

Secondly, the trajectories of the most recent years vary considerably from one year to the next. This is the main problem in terms of producing consistent advice from one year to the next. The parallel shifts have mainly implication for the stock status of the "current year" and when one year is viewed across different assessments the estimates are not significantly different. However, when the trajectory changes from one year to the next on top of this and thus the perception of stock status, response to fishing and cod predation, the advice derived from the model also jumps around from one year to the next.

To address these concerns, a small group composed of AnnDorte Burmeister, Frank Rigét and Carsten Hvingel met in Tromsø during the second week of April 2018 to further explore and evaluate the performance of the West Greenland shrimp stock assessment model and if possible to propose model improvements. We wanted to address:

1. What is the implication of using a thirty-year moving time window?
2. Evaluate and possibly revise input priors
3. Look for evidence of time-shifts in model parameters
4. Revise the model according to potential new findings

The thirty-year time window

In 2011, the model was changed from applying input data that covered the full length of the available time-series (since 1976) to only be based on the most recent 30 year period. An evaluation of the implication was described in detail in the appendix of Kinsley (2011). The main advantages of this approach were:

- The model run faster
- Less "historical loading" (i.e. less sensitivity to assumption about time invariant parameters)
- Makes little difference to results

A comparison was made between the "30 years input" model and a model including input back to 1976 (Kinsley, 2011). Based on a comparison of MSY, B/B_{msy}, Z/Z_{msy} and CV's on CPUE, survey, predation and process error between the two runs NIPAG concluded that the effect of shortening the data series was not significant (NIPAG SCS 11/20). NIPAG did however not address nor investigate whether this conclusion would be valid also for future years.

A model based on the full series of data assume that associated ecosystem parameters influence on the stock dynamic on the same way during the whole period (model parameters like e.g. K, MSY or q are time invariant). If this assumption is wrong, this could lead to biased estimates of key parameters. A shift in the temperature regime during the period could be one example. By reducing the time span modelled to a thirty year period the model assumption of "stable" (=varying randomly) ecosystem related parameters could make violation of this assumption less problematic. On the other hand, reducing the time span to thirty year might mean throwing away data that holds important information on model parameters. E.g. the cod abundance in West Greenland in the beginning of the period relevant for the shrimp assessment model were much higher than it has been in the latest twenty nine years and the model gains lots of its information about how cod influence shrimp biomass from that period. Furthermore, the years with Grunwald data used to estimate the cod predation are now starting to disappear out of the thirty-years-window. I.e. model "knowledge" of the cod-shrimp interaction is gradually being lost as older data is deleted to accommodate the thirty-year-window approach.

Another effect of the thirty-year-window approach is that the parameter assigned to biomass in the first year (Pzero), changes with every yearly assessment update – it is no longer assigned to a fixed nominal year but to year+1 with every update. However, in the way the model was run Pzero was not reset (its prior was reevaluated) each of the following years when the time window moved and this might have influenced results in unforeseeable ways in particular when in a period of strong population dynamics.

Based on the considerations above we set out investigation establishing a "baseline".

Run: Baseline 1

The assessment model was run applying the full time-series back to 1976 and without changing anything else in the model setup (i.e. with the settings used in the 2017 assessment).

In general, the parallel shift from year to year appear to be less pronounced by applying the full time-series (Fig. 2) compared to the model using a moving 30 years window (Fig. 1). The model based on the time-series from 1976 to 2007 (violet curve in Fig. 2) is the exception. However, the trajectories of the most recent years are still changing considerably from year to year.

Table 1 shows that the mean annual change of MSY was reduced from 6.5% to 4.0% when applying the full time-series to the model (Baseline 1) compared to applying the 30-years moving time window (2017 assessment). The reduction was even larger when comparing with the actual NIPAG assessments (7.1% to 4.0%), where the model has been subjected to changes during the period 2013 to 2015 (see Kingsley, 2015).

In conclusion, the stability of the model was improved by applying the full time-series; however there are still some instability in the retrospective plots.

The assumption about time invariant parameters

We then went to look for regime shifts in the West Greenland ecosystem and major turnarounds in the fishing patterns of the shrimp trawlers and the fleet, which violate the assumption of time invariant parameters.

The catchability parameters

In the assessment model both the survey and the commercial CPUE data series are included as indices of shrimp stock biomass scaled by time invariant catchability parameters q_{survey} and q_{CPUE}. Hvingel and Kingsley (2006) using data up until 2002 highlighted a very good correlation between the survey and the CPUE indices; however, this appears no longer to be the case with the addition of new data (Fig. 3).

During the period 1988 to 2002, the relationship between the two indices was indeed well and positively correlated. In the following period 2003 to 2006/2007 where the survey indices decreased considerably, while the CPUE increased, their relationship is reversed. Since 2007 a positive correlation between the two indices is restored, but with CPUE index values considerably higher compared to the earlier period with comparable survey index values. As the survey indices stem from a carefully standardized and well managed scientific survey the observed changes in the trajectory of the survey-CPUE indices likely indicate a significant shift in the catchability of the commercial fishery.

Replacements in the fleet

In the 2001 – 2003, several older trawlers were replaced by new large and modern trawlers (Akamalik, Nataarnaq, Qaqqatsiaq and Regina C, all around 3000 GRT). Engine size and the storing capacity were increased compared to the vessels they replaced. This restructuring of the trawler fleet may have affected the overall effectiveness of the fishery considerably and increased the catchability in ways not captured by the CPUE standardization model (Hvingel et al. 2000) at least during the transition period.

Water temperature

Significant changes in the environment was also observed in the late 1990s to early 2000s. The bottom temperature increased during the mid- to late 90s (Fig. 4), and in the beginning of 2000s the shrimp survey biomass moved north and into shallower water (Fig. 5).

Fishery distribution

The changes in the distribution of shrimp as observed in the survey is mirrored in the fishing pattern of the commercial trawler. During the period 2002-2006 the fishery gradually moved northward after a period of approximately 20 years where shrimp fishery in the south (south of 66 N) were dominating (Fig. 6). In this period the catches increased considerably (Fig. 7), and at same time the CPUE increased and survey biomass decreased (Fig. 3). Furthermore, the fishery in that period were also in more shallower waters than both before and after (Fig. 8).

The increased bottom temperature followed by a changed distribution of the shrimp biomass, which further leads to changes in the geographical and depth distribution of the fishery may have added to the observed shift of the catchability in the commercial fishery. The period 2003 to 2006 with its major changes may be considered as a “transition period” before a new “balance” were obtained between the shrimp biomass and the commercial fishery.

Thus a shift in the catchability in the commercial fishery during the early to mid 2000s as indicated from the Survey-CPUE relationship (Fig. 3) can be underpinned by both changes in the fishery and in the distribution of the resource. The period 2003 to 2006 may therefore be considered a “transition period” where the previous survey-CPUE relation deteriorates and the CPUE indices from that period is no longer reflecting stock biomass. Once through this period, a new the Survey-CPUE relation is established (Fig. 9).

Revised relationships between survey and CPUE indices
In conclusion, this analysis suggest that the assumption of a time invariance for the parameter that scales the CPUE indices to stock biomass (q_{CPUE}) is indeed an oversimplification. And, that the model could be improved by including some type of time variance for q_{CPUE} to allow for it to vary for the 3 different time periods (Fig. 9).

In a new version of the assessment model we therefore implemented a time-variable catchability of the CPUE by assigning a different q's to the periods 1988 to 2002 and 2007 to 2017

$CPUE_t = q_{c1} P_t \exp(\omega_1)$, for $t \in (t_{1988}, t_{1989}, \ldots, t_{2002})$

$CPUE_t = q_{c2} P_t \exp(\omega_2)$, for $t \in (t_{2007}, t_{2008}, \ldots, t_{2017})$

Here are q_{c1} and q_{c2} catchability constants for the two periods, P_t is the stock biomass relative to biomass at MSY, and ω_1, ω_2 are their error terms.

We did not try to model the "transition period" (2003 to 2006). Firstly, it would be difficult to assume one common q for that period when it is suggested to change a lot and non-linear relationship would therefore be needed. For modelling just four points, this would likely lead to overparameterization. In addition, we do have survey information for those years which should provide sufficient information for the model. In the new version of the assessment model we therefore deleted the CPUE data for those years.

Evaluation of existing priors

The priors used in the assessment model has largely remained unchanged since (Hvingel and Kingsley 2005). We went through the list of priors as formulated in the 2017-model to see whether updates could be proposed (Table 3, Fig. 10). In general, only minor adjustments were found necessary. They included trimming of the probability distributions so they would not assign any likelihood to very high or low unrealistic values and were mainly done out of technical considerations i.e. to improve the run-time of the model.

In a few instances, however, more substantial changes were warranted. In 2011 the priors on the variances of the survey and CPUE indices of the assessment model were changed from being uninformative gamma-distributed to an informative uniform prior from 0.1 to 0.2 on the CV for the survey and let the CV of the CPUE be a multiple (between 1 to 10) of the survey CV. By doing this the CPUE CV would always being greater than the survey CV (Kingsley, 2011). The reason for this change was that the modelled biomass trajectory closely follow the CPUE series and nearly ignored the survey series.

This change was done in 2011 as a response to a short period where the survey index decreased substantially since the peak in 2003. At the same time the CPUE remained relative stable (Fig. 3) and so did the model estimated biomass series. In any case, while this *ad hoc* fix made it easier for the model to follow the downward survey trend from 2003 to 2007 it also made it more sensitive to the following year-to-year variations in the survey, which can be large. With the introduction of a time variant q for the CPUE index and the omission of 2003-2006 from the input CPUE index (see above), the primary reason for introducing the CV-constraint is no longer present and can be removed.

Results from the Baseline 2 model

Table 2 shows that the mean annual change of MSY was reduced from 4.0% to 2.6% when comparing the time variant model (Baseline 2) with the time invariant model (Baseline 1). This indicates that the Baseline 2 model gives a further stabilization of the estimation of MSY compared to the Baseline 1 model and the 2017 assessment model with a thirty-year data window.

The ten-year retrospective plots of the estimated relative biomass by Baseline 2 model indicates a further stabilization of the model (Fig. 11) compared to the baseline 1 model (Fig. 2). The parallel shift in the Baseline 2 models estimates of the relative biomass between assessments year decreases and the trajectories of the most recent years are changing less. However, there are still some parallel shift of the trajectories (2010 and 2011) and some years with deviations from one year to the next (2013-14 and 2016-17). However, not excessively large and not statistically significantly corrections

Model performance

The process error for Baseline 2 are shown in Fig. 12. There is a tendency of the process error to go from being mostly negative to being mostly positive from 1976 to 2002. During the years from 2002 to 2006 the process error falls from about 0.2 to close to -0.2. This coincides with the years where the CPUE data has been removed from the model. After 2006 until now an increasing trend in the process error are observed again. This temporal pattern is also evident when plotting the process error for Baseline 1 and the 2017 assessment model showing that the Baseline 2 model has "inherited" this pattern rather than has "created" the pattern. The serial correlation in the process error was estimated to be 1.1% with quartile points at ± 10.1%.

The model was able to produce a reasonable simulation of the observed data (Fig. 13). The probabilities of getting more extreme observations than the realised ones given in the data series on stock size were generally inside the 90% confidence limit (Table 4). The CPUE series was generally better estimated than the survey series. However, the model did not captured the survey peak around 2004. Otherwise, no major problems in capturing the variability of the data were detected.

Conclusions and recommendations

In conclusion, we find that the model performance was satisfying. The Baseline 2 model is considered more stable in its estimation of the MSY parameter but also when judged from the trajectories of the retrospective plots compared to the thirty-year time window model applied in the 2017 assessment. We recommend applying the Baseline 2 model in shrimp assessment in 2018.

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Table 1. MSY and annual change of MSY estimated by assessment model based on the full time-series (baseline 1) and based on 30 years moving time window using the 2016 model and actual NIPAG assessment.

Model based on full time-series			Model based on 30-years moving time window					
Baseline 1			2017-assessment			NIPAG assessment		
Year	MSY	% change	Year	MSY	% change	Year	MSY	% change
1976-2007	118.5		1984-2013	123.9		1984-2013	138	
1976-2008	113.7	4.1	1985-2014	118.8	4.1	1985-2014	131.3	4.9
1976-2009	114.3	0.5	1986-2015	131	10.3	1986-2015	140.2	6.8
1976-2010	113.7	0.5	1987-2016	126.7	3.3	1987-2016	126.7	9.6
1976-2011	112.5	1.1	1988-2017	137.4	8.4	1988-2017	134.7	7.1
1976-2012	107.4	4.5		**mean**	**6.5**		**mean**	**7.1**
1976-2013	112	4.3						
1976-2014	105.6	5.7						
1976-2015	116.1	9.9						
1976-2016	113.3	2.4						
1976-2017	121.4	7.1						
	mean	**4.0**						

Table 2. Comparisons of MSY and annual change of MSY between baseline 2 and baseline 1 models

	Baseline 2		Baseline 1	
Year	MSY	% change	MSY	% change
1976-2007	139.7		118.5	
1976-2008	130.8	6.4	113.7	4.1
1976-2009	128	2.1	114.3	0.5
1976-2010	130.8	2.2	113.7	0.5
1976-2011	129.1	1.3	112.5	1.1
1976-2012	124.4	3.6	107.4	4.5
1976-2013	121.2	2.6	112	4.3
1976-2014	118.2	2.5	105.6	5.7
1976-2015	122.5	3.6	116.1	9.9
1976-2016	122.3	0.2	113.3	2.4
1976-2017	124.5	1.8	121.4	7.1
	mean	**2.6**	**mean**	**4.0**

Table 3. Priors used in the 2017 version of the assessment model and suggested updated if any

	Prior		
	formulation		
parameter	2017-model	2018-update	Comment
Pzero	*~dlnorm(0,15)*	no	Introduces in the 2015 assessment and is wider than the previously used
MSY	*Lgt.MSY~dunif(1,3)*	*~dunif((1,500)*	Changed from uniform log-space to uniform in real space. Made little difference to the posteriors and could have been omitted
K	*~dlnorm(6.67,1)*	*~dlnorm(6.67,1)|(,1000)*	Censored to avoid high unrealistic values
qs	*Logt.qs~dunif(-3,20)*	*~dunif((-5,3)*	Changed from uniform log-space to uniform in real space
q	*Logt.q~dunif(-3,3)*	*Logq1~dunif(-5,3)* *Logq2~dunif(-5,3)*	Separated q for two periods (1976-2002) and (2007-2017)
cvsurv	*~dunif(0.1,0.2)*	*~dunif(0.1,0.4)*	Made wider resulting in a "nicer" posteriors plot
cvcpue	*cv<-cvsurv*relative.cv*	*cvcpue1~dunif((.05,1)* *cvcpue2~dunif((.05,1)*	Time variant catchability. Low informative
Related to cod shrimp interaction		no	

Table 4. Model diagnostics: Residuals (% of observed value) and probability of getting a more extreme observation (Pr).

	Survey		CPUE1		CPUE2	
Year	resid(%)	Pr	resid(%)	Pr	resid(%)	Pr
1976			-2.2	0.59		
1977			-3.7	0.67		
1978			3.5	0.34		
1979			7.3	0.20		
1980			-6.0	0.77		
1981			6.9	0.20		
1982			-8.4	0.86		
1983			1.2	0.44		
1984			3.3	0.34		
1985			-0.2	0.51		
1986			4.3	0.30		
1987			-8.1	0.85		
1988	-5.3	0.59	4.7	0.29		
1989	-10.9	0.75	2.5	0.37		
1990	-14.1	0.81	1.0	0.45		
1991	23.6	0.11	0.1	0.49		
1992	-2.2	0.56	-2.3	0.61		
1993	-9.8	0.73	1.7	0.41		
1994	-11.1	0.76	3.5	0.34		
1995	12.5	0.24	-2.0	0.59		
1996	9.7	0.29	-4.2	0.71		
1997	30.2	0.06	1.5	0.42		
1998	-0.9	0.52	-2.4	0.61		
1999	15.1	0.22	-1.5	0.56		
2000	4.2	0.41	-4.7	0.73		
2001	9.7	0.30	5.0	0.27		
2002	-3.7	0.60	1.1	0.44		
2003	-22.2	0.92				
2004	-13.3	0.76				
2005	-12.2	0.75				
2006	-18.1	0.87				
2007	-8.9	0.71			9.3	0.16
2008	6.0	0.36			-3.6	0.68
2009	3.9	0.41			2.4	0.39
2010	-18.3	0.88			3.5	0.35
2011	2.4	0.45			-3.6	0.66
2012	30.3	0.07			-4.0	0.68
2013	-1.5	0.55			2.4	0.39
2014	27.8	0.08			-2.2	0.59
2015	-10.5	0.75			-1.3	0.56
2016	22.5	0.12			2.2	0.40
2017	-4.9	0.62			-5.8	0.75
2018	-0.1	0.50			3.3	0.40

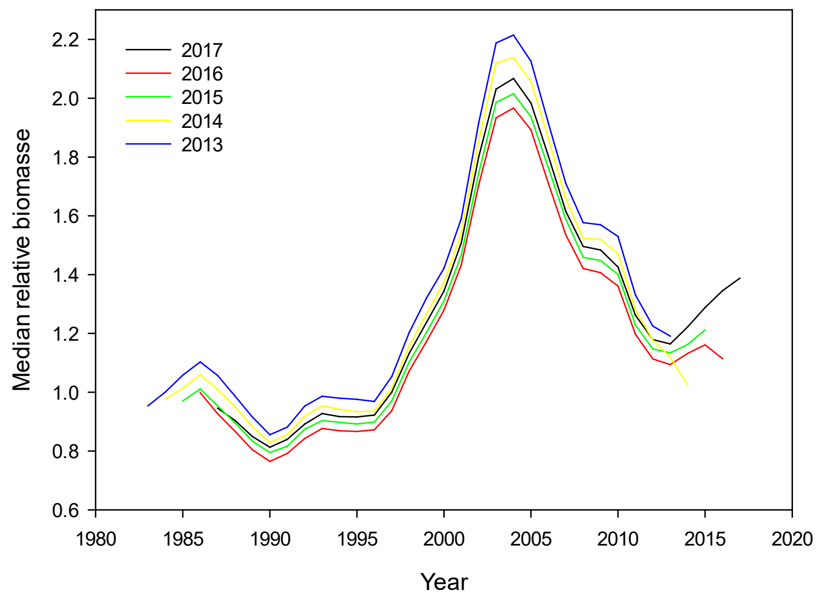

Fig. 1. Five-year retrospective plot of model estimated median shrimp stock biomass (NIPAG 2017).

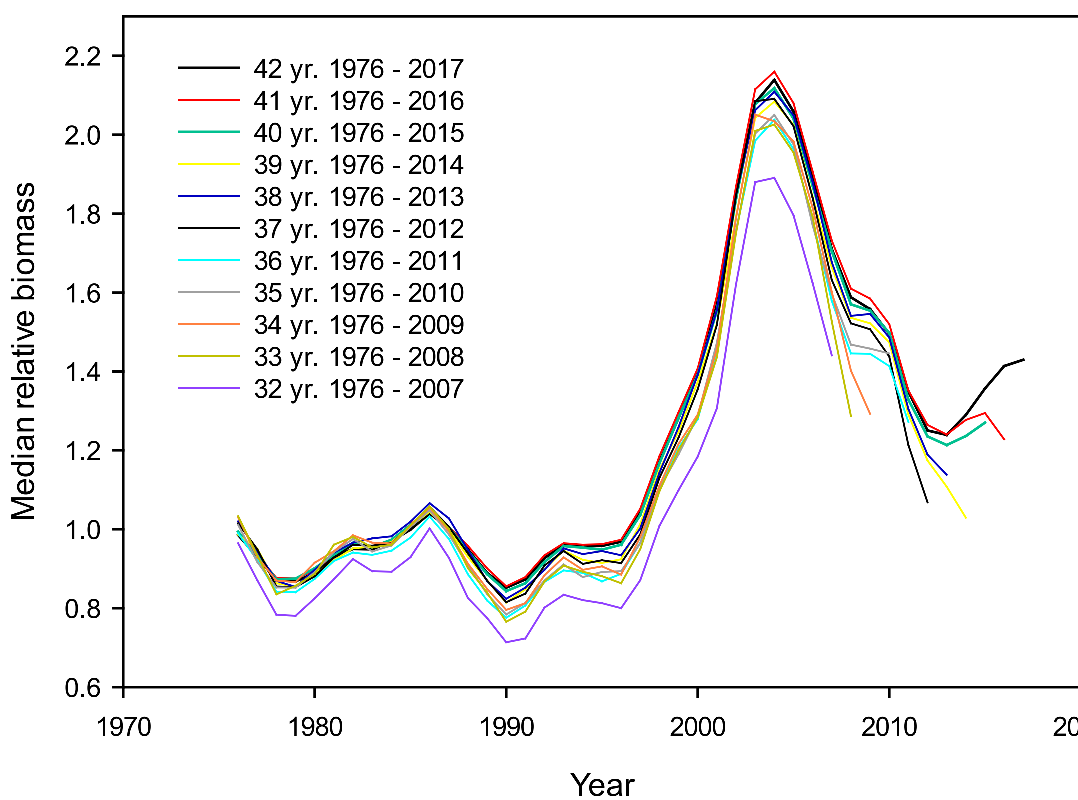

Fig. 2. Ten-year retrospective plots of the 2017 assessment model using the full time-series going back to 1976 to 2017 (Baseline 1).

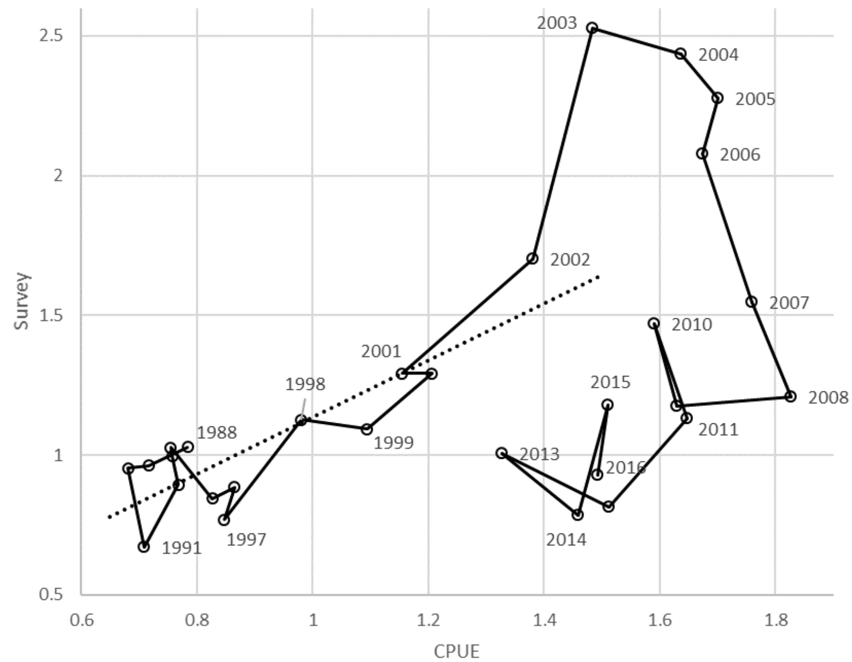

Fig. 3. Relationship between the survey and CPUE index 1988 to 2017 (survey began in 1988). The dashed line show the relationship as reported by Hvingel (2006) for the period up to 2002.

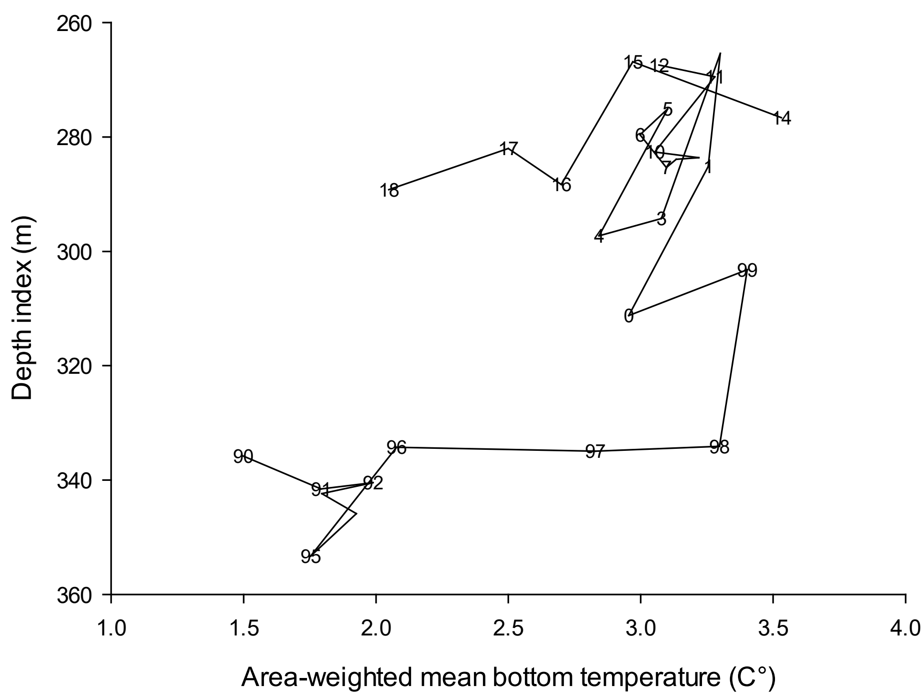

Fig. 4. Depth index of survey biomass vs. area-weighted mean bottom temperature from survey trawl-door measurements, 1990–2018.

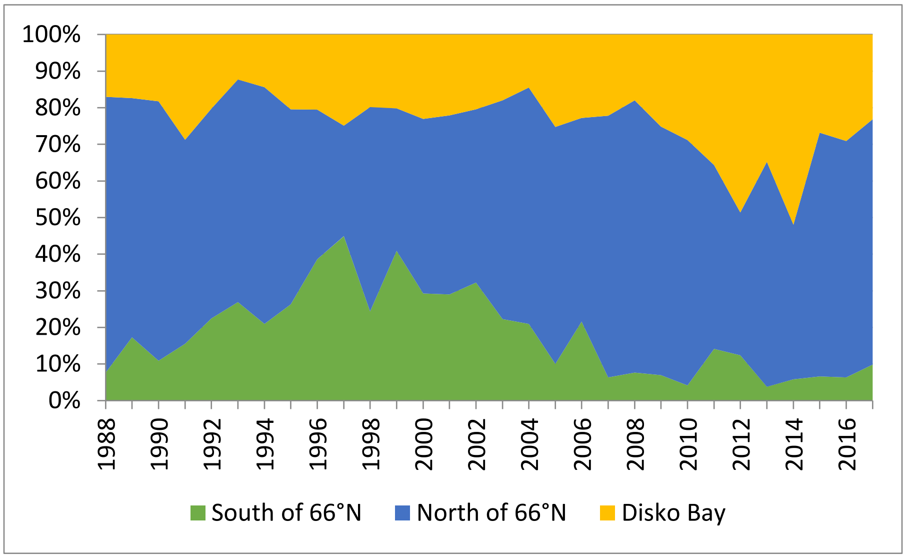

Fig. 5. Distribution of survey biomass between major survey regions, 1991 – 2018.

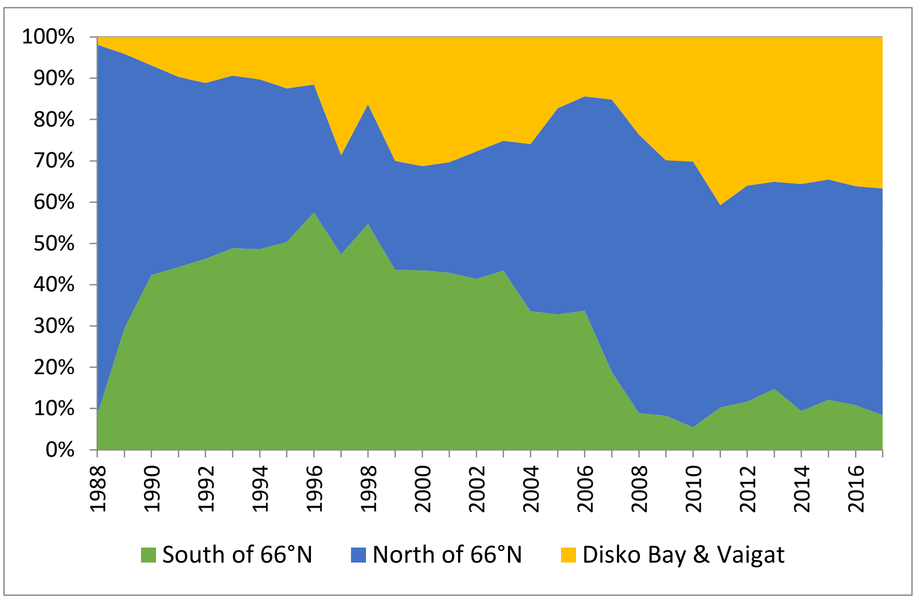

Fig. 6. Relative distribution of the commercial shrimp fishery effort.

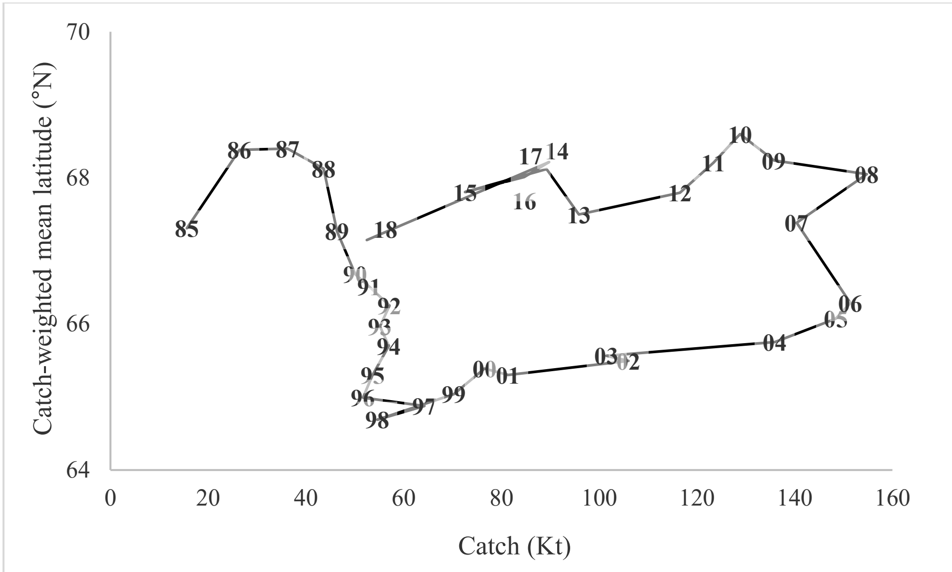

Fig. 7. Catch-weighted mean latitude (°N) vs catch.

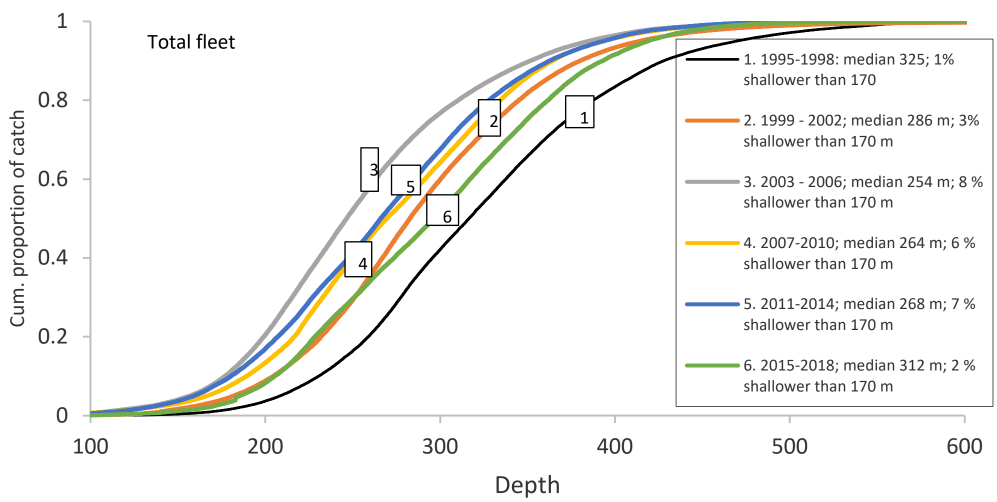

Fig. 8. Proportions of catch by depth in different time periods.

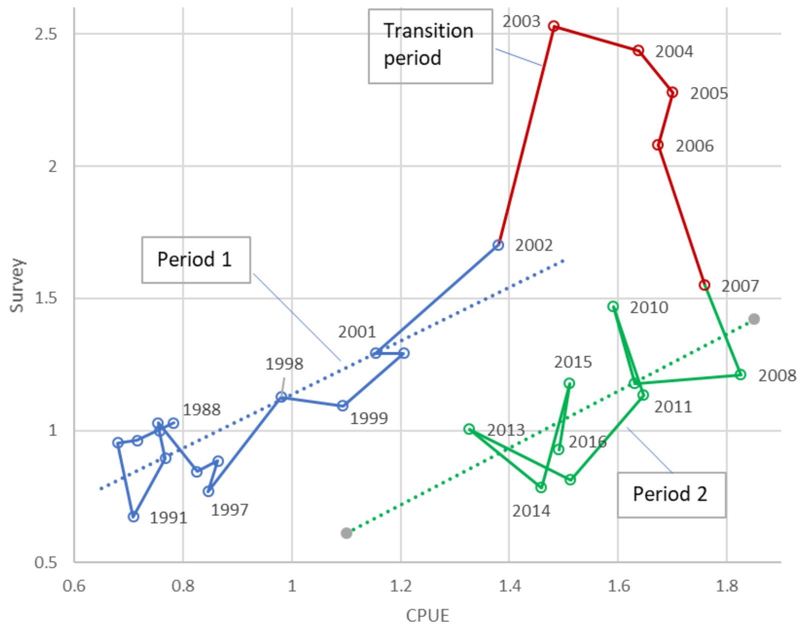

Fig. 9. Relationship between biomass indices from the scientific survey and the commercial Catch-Per-Unit-Effort (CPUE). Dashed lines are ordinary least squares regression.

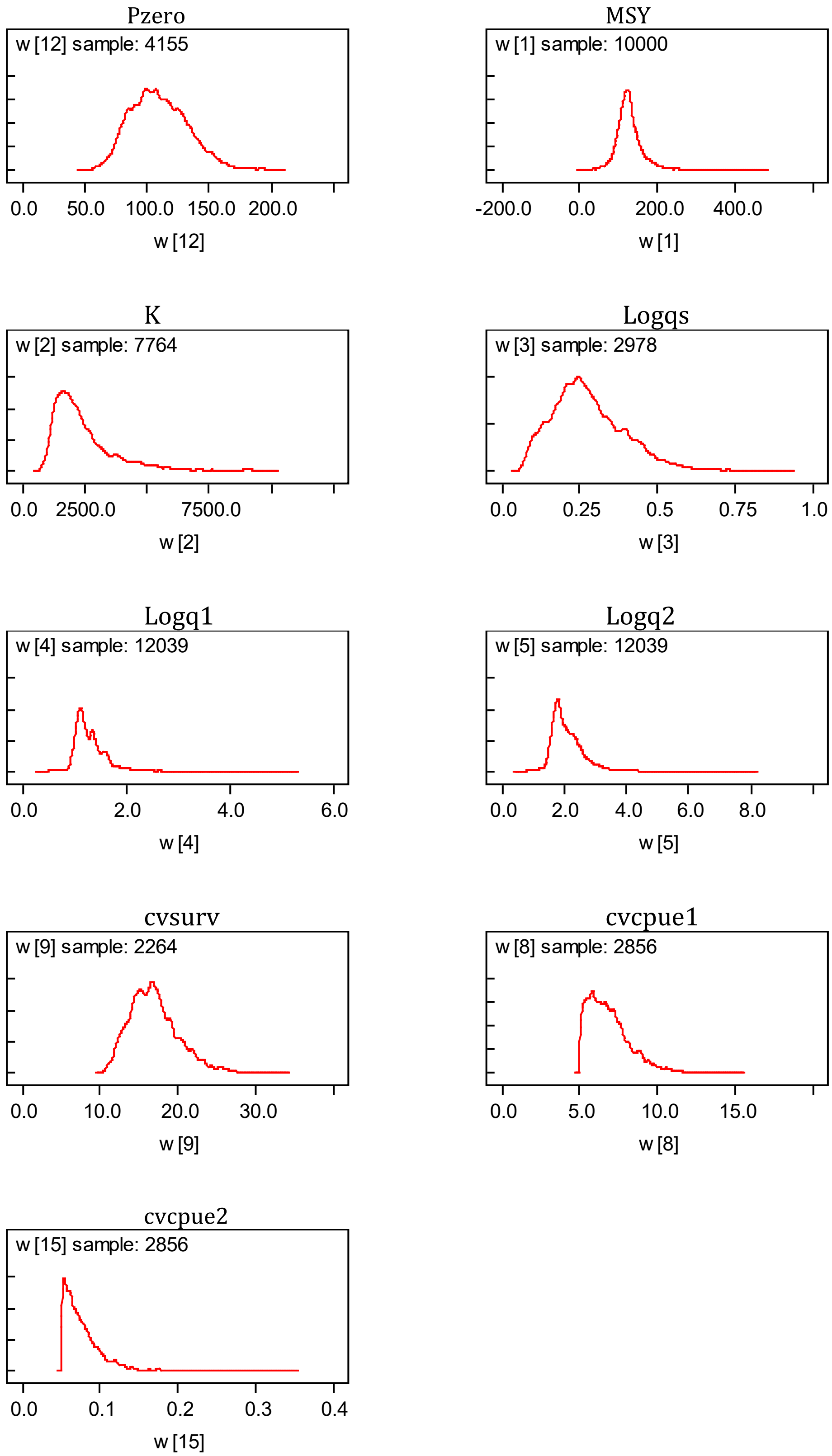

Fig. 10. Prior posterior density plots.

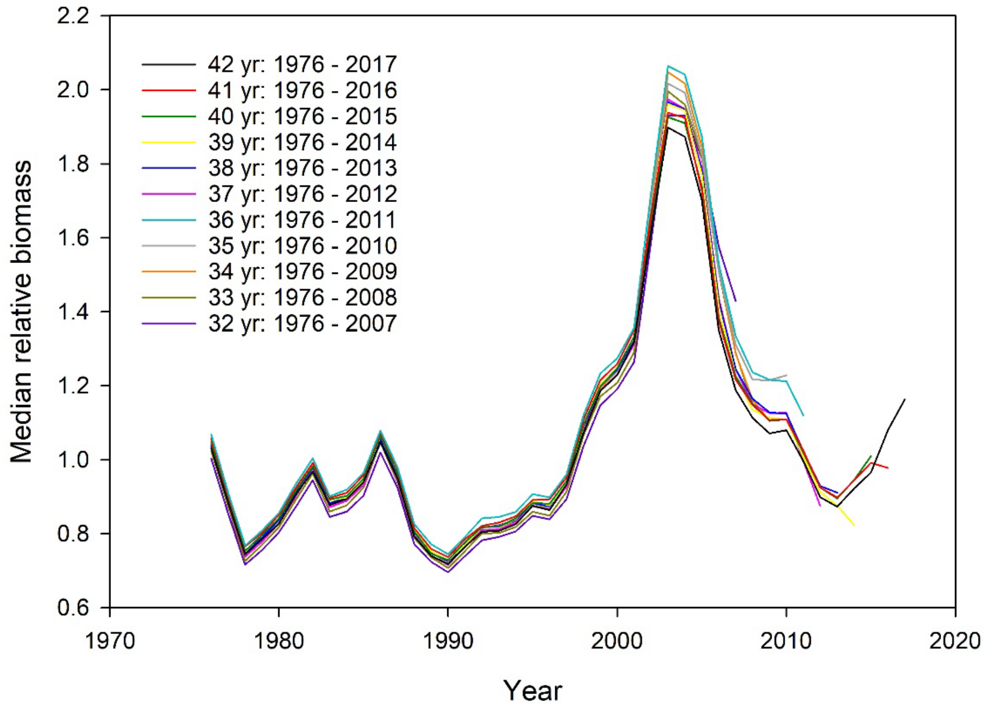

Fig. 11. Ten-year retrospective plots of the 2017 assessment model using the full time-series going back to 1976 to 2017 (Baseline 1).

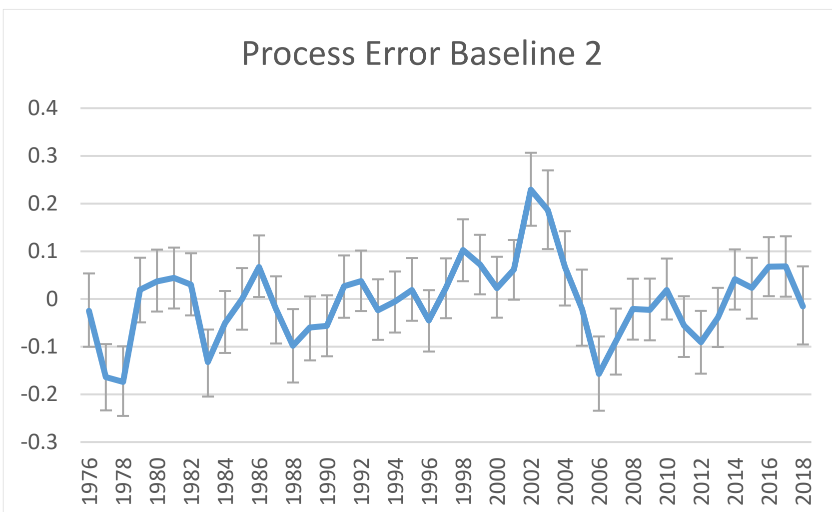

Fig. 12. Process error plot for Baseline 2.

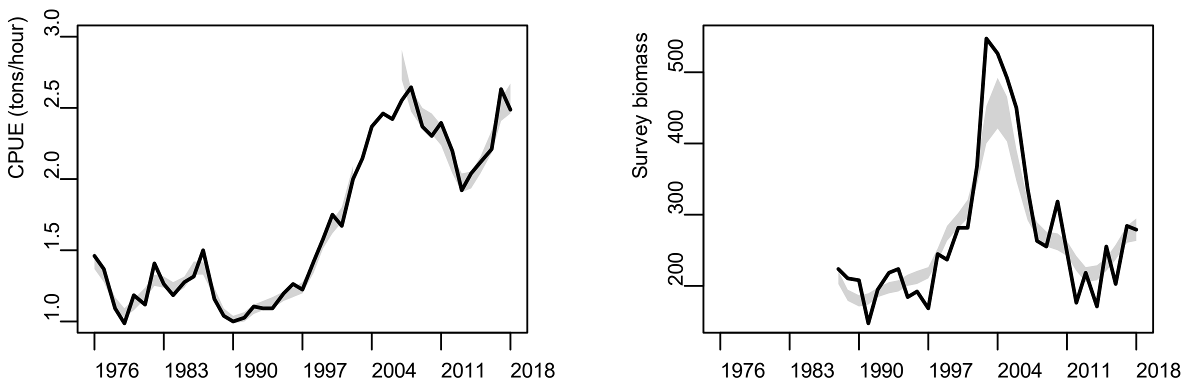

Fig. 13. Observed (solid line) and estimated (shaded) series of the biomass indices. Gray shaded areas are 25% - 75% inter-quartile range of the posteriors.