Pink ling stock assessment for 2018

Final report

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Executive summary

This document presents the final assessment results for ISL's assessment of pink ling in 2018. It was an update of the 2015 assessment in that essentially the same methods were applied and new data were added to existing time series.

However, the estimation of "period effects" in the eastern trawl CPUE analysis, which was done in the 2015 assessment, was not successful in this assessment. The period effects were to deal with the different management regimes (in terms of trip limits) that have been in effect for some years. But, when they were estimated the subsequent CPUE time series had an unrealistic increase in 2016 and 2017. Instead of using the period-effect CPUE time series the estimated discard ratios were applied to tow by tow data before the CPUE standardisation. Essentially this is an adjustment from landings to catches (on average) in the periods when there was significant discarding due to management measures. However, this time series takes no account of avoidance behaviour by fishing vessels (not picked up by standardisation) which may have occurred because of the management measures.

For the eastern stock, current stock status is estimated at 30% B_0 with a 95% CI of 22–42% B_0. The uncertainty in estimated stock status was amplified in the estimation of RBC which is estimated at 260 t with a 95% CI of 36–560 t. However, when a full Bayesian assessment is available to perform risk analysis, the use of a generic control rule is not needed to provide management advice on TACs.

Stochastic projections were performed for the eastern stock for a range of constant catch strategies from 300 t to 650 t per year. According to projections from the base model there is little risk to the stock over the next few years for total removals up to 550 t per year. Expected spawning biomass increases from 2021 to 2028 for annual catches up to 600 t per year. The stock is expected to rebuild to the target of 48% B_0 with at least 50% probability in a reasonable timeframe (before 2050) for annual catches up to 500 t per year.

For all of the eastern models, including the two that estimate the lowest current stock status, the spawning biomass is expected to increase from 2021 to 2028 for constant annual catches of 500-550 t. The risk of falling below the limit reference point (20% B_0) decreases over time for all of the models at annual catches of 500-550 t. Annual long-term yield is estimated at 540-620 t (95% CI).

For the western stock, current stock status is estimated at 84% B_0 with a 95% CI of 69–100% B_0. RBC is estimated at 1150 t with a 95% CI of 770–1660 t. Annual long-term yield is estimated at 550–860 t (95% CI). Stochastic projections show little or no risk to the stock in the next few years for total removals of up to 1000 t per year.

Introduction

ISL was contracted by AFMA to update the 2015 eastern and western pink ling stock assessments (Cordue 2015). Also, CSIRO was contracted by AFMA to provide raw and processed data to ISL to enable the assessments (as they did in 2013 and 2015).

The assessment was performed from August to November 2018. Initial progress was presented at the 19-21 September SERAG meeting in Hobart. The initial work including the updating of the catch history and trawl CPUE time series for both the eastern and western stocks. At the September meeting preliminary updates were presented but these were only MPD estimates (rather than MCMC estimates – the two types of estimates are described below).

At the second SERAG meeting (14-16 November 2018 in Hobart) the final assessment was presented. On the first day of the meeting the SERAG was offered three choices for an eastern base model: the reference model (originally chosen as the base at the first SERAG meeting but without knowledge of the value of the MCMC estimate of natural mortality (M) which occurred); a variation of the reference model where M was fixed at the estimate from the western assessment; and an alternative trawl CPUE time series where M was also fixed at the estimate from the western assessment. The variation of the reference model with M=0.23 was chosen as the base model. RBC was estimated for the new base model and constant catch projections were performed for this model. The results were made available to the SERAG in the final two days of the meeting. The western assessment was also presented being essentially just the MCMC results for base model agreed at the previous SERAG (with estimates of RBC and constant catch projections).

This report describes the methods and results of the assessment in detail. However, for the eastern assessment, many of the sensitivity runs are sensitivities to the Reference model rather than to the base model. This is a necessary shortcut because of the change in the base model very late in the project. The main sensitivity to assessment results is the treatment of M. This effect is fully covered by the runs presented.

Methods

The eastern and western pink ling stock assessments were updated using the methods described in Cordue (2013, 2015). The details are given below and in the appendices.

Catch histories

The catch histories for each stock by method (trawl and non-trawl) were available from the previous assessment to the end of 2015. The catch histories were revised and extended to the end of 2018 as described in Appendix A. The extension of the catch histories was complicated by the need to estimate discards since 2013 due to trip limits placed on the eastern trawl fishery. In the east, the trawl fishery catches dominate those from non-trawl methods (Figure 1). In the west, lower catches have been taken than in the east and the non-trawl methods are recently taking similar but lower levels of catch to trawl (Figure 2).

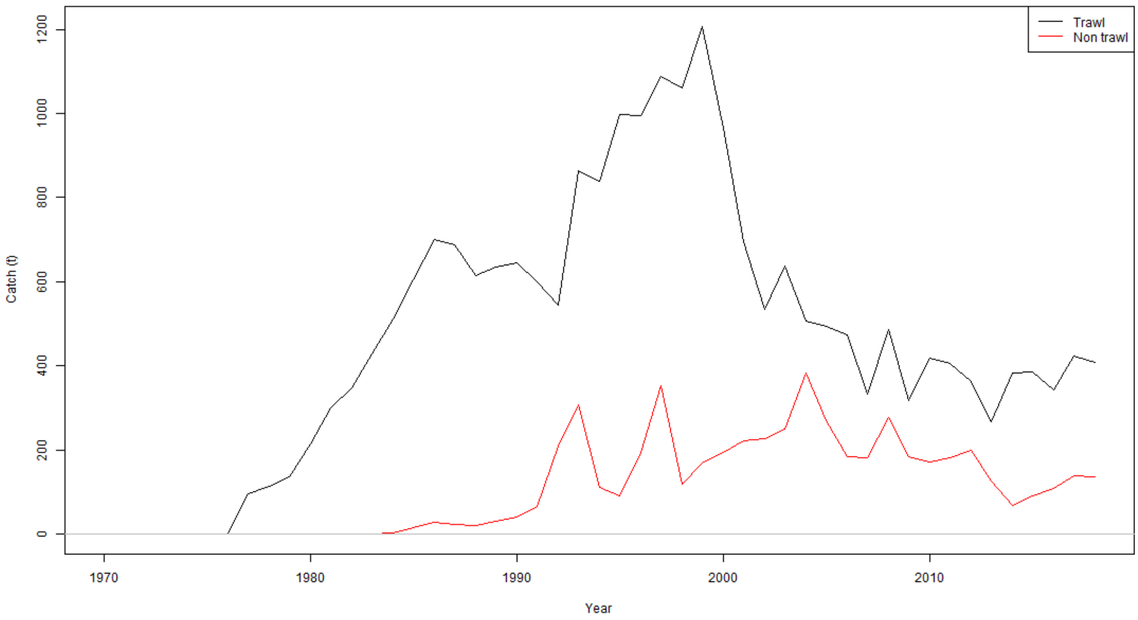

Figure 1: Eastern base model: catch history for the trawl and non-trawl fisheries by calendar year.

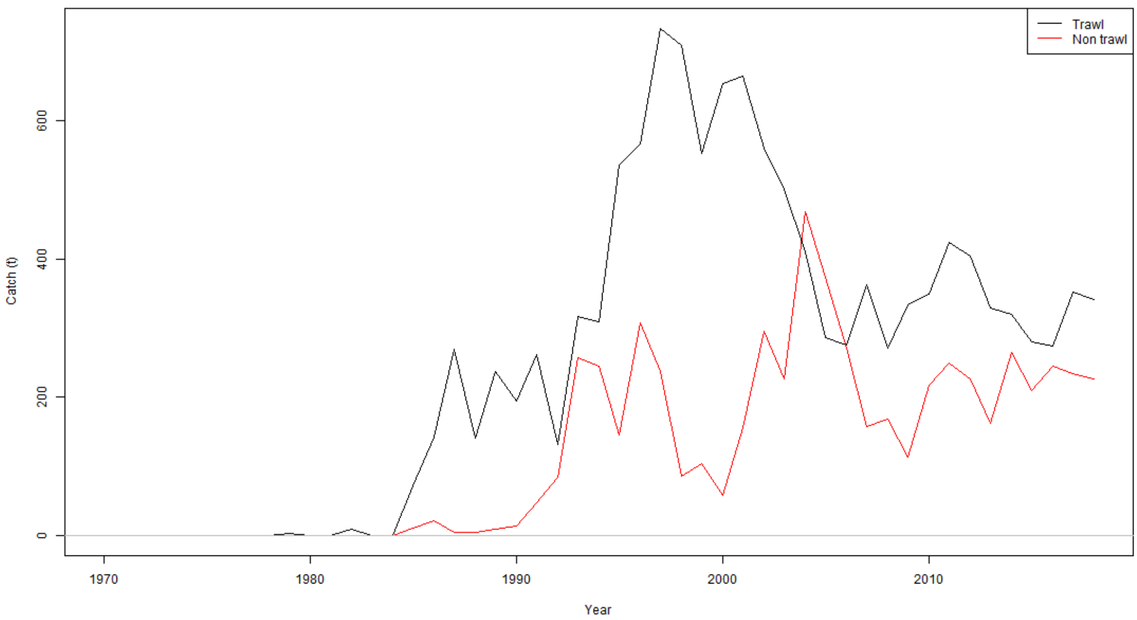

Figure 2: Western base model: catch history for the trawl and non-trawl fisheries by calendar year.

Trawl CPUE indices

The eastern and western trawl CPUE indices were updated to the end of 2017 as described in Appendix A. As in 2015, "period" effects were estimated for the eastern stock to deal with the periods of time during which different trip limits were in effect (see Appendix A).

However, the approach taken in 2015 was not successful as the year effects estimated for 2016 and 2017 were unrealistically high. Instead of estimating period effects the individual trawl landings were adjusted (on average) to total catches (landings plus estimated discards) before standardization (see Appendix A). This resulted in a CPUE time series that was very similar to that used in the base model in the 2015 assessment (Figure 3). The RAG agreed to use this CPUE time series in the base stock assessment model.

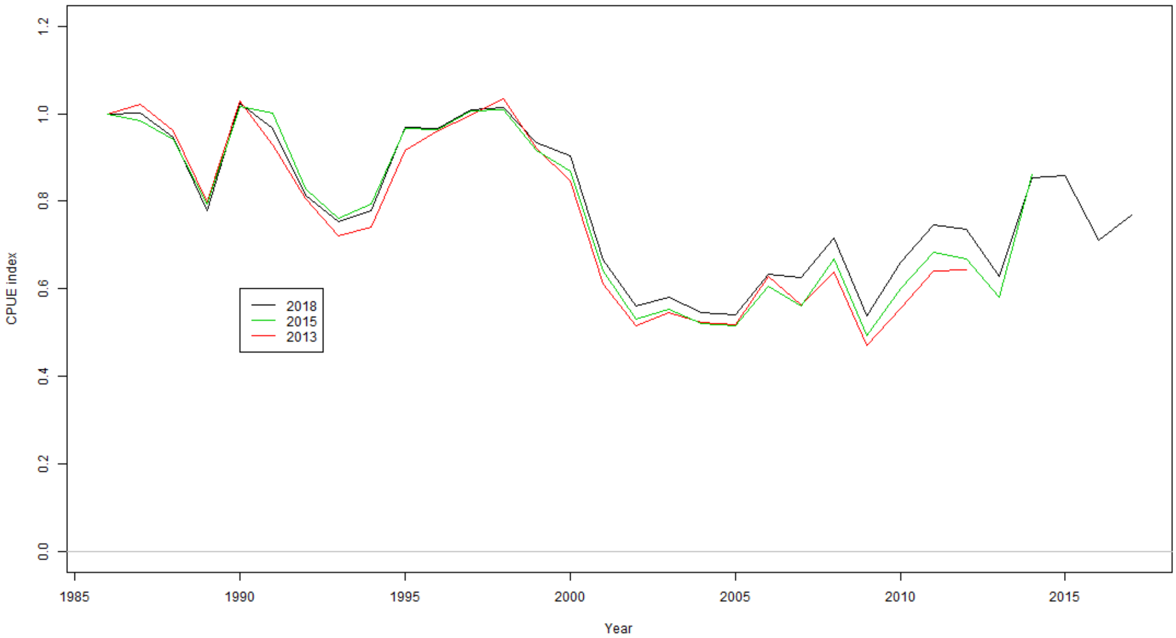

Figure 3: Eastern trawl CPUE comparing the base models in 2013 and 2015 with the 2018 model where the individual trawl landings were adjusted for discards before standardization.

There were no major complications for the western trawl CPUE time series and this was updated to the end of 2017 (Figure 4). It appeared that some of the western vessels were given updated callsigns from 2000 onwards and so were represented in the 2018 dataset by more than one callsign. A comparison of the 2015 and 2018 datasets revealed that few vessels were affected and the corrected CPUE time series was almost identical to the preliminary series.

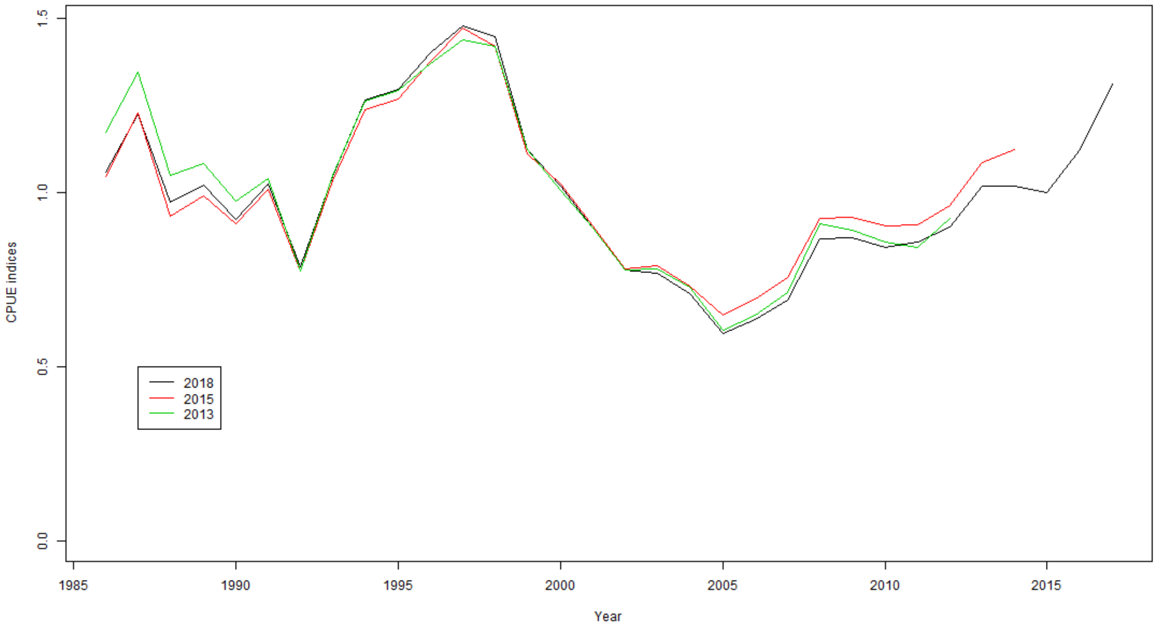

Figure 4: Western trawl CPUE comparing the 2013 (base model), 2015 (base model) with the 2018 standardized indices.

Commercial composition data

For the eastern and western stocks, length frequency data by method (trawl, line), zone, sampling type (port, onboard), and depth stratum (0-300 m, 300-500 m, 500+ m)(samples scaled to individual catches) were supplied by CSIRO. Raw age-length data were also supplied (for which standard length measurements were converted to total length where appropriate).

The length frequency data were stratified and scaled following the 2013 assessment (Cordue, 2013). In the east, stratification was by depth and zone for the trawl data (which precluded the use of port samples) and by zone for line. For the west, there was no stratification (but the samples for some years were omitted where there were very few operations and/or fish).

The age-length data were also stratified and scaled for eastern trawl following Cordue (2013). Non-sexed age-length data (almost all from Zone 20) were used to construct age-length keys which were applied to the corresponding length frequencies to produce age frequencies for the eastern assessment.

The tables below give the years for which composition data were used in the base models (years with port-sampled length-data are in red).

	Length frequencies		**Conditional age-length**		**Age frequencies**	
	Trawl	**Line**	**Trawl**	**Line**	**Trawl**	**Line**
East			1979			
			1994			

			1995			
			1996			
	1998		1998			
	1999		1999			
	2000					
	2001		2001			
	2002	2002, 2002				
	2003	2003		2003		
		2004, 2004		2004		
	2005	2005	2005			
	2006	2006, 2006				
		2007				
						2008
				2009		2009
			2010		2010	2010
			2011	2011	2011	2011
		2012		2012	2012	
		2013		2013		
		2014				
			2015	2015	2015	
	2016					
	2017					

	Length frequencies		**Conditional age-length**	
	Trawl	**Line**	**Trawl**	**Line**
West			1987	
	1992			
	1993			
	1994			
	1995, 1995		1995	
	1996, 1996			
	1997, 1997		1997	
	1998, 1998		1998	
	1999, 1999		1999	
	2000, 2000			
	2001, 2001	2001		2001
	2002, 2002	2002	2002	
	2003, 2003	2003	2003	2003
	2004, 2004	2004	2004	2004
	2005, 2005	2005	2005	2005
	2006, 2006	2006	2006	2006
	2007	2007		2007
	2009			
	2010	2010	2010	2010
	2011		2011	
	2012	2012	2012	2012
	2013	2013	2013	2013
	2014	2014	2014	2014
	2015	2015	2015	2015
	2016			
	2017			

Fishery independent survey data

The winter Fishery Independent Survey (FIS) time series for pink ling was supplied by CSIRO. Estimates were available for the eastern and western stocks:

	Eastern		Western	
Year	**Index**	**CV (%)**	**Index**	**CV (%)**
2008	19.1	21	9.3	21
2010	23.4	22	10.6	21
2012	25.9	22	11.4	22
2014	23.8	21	20.0	20
2016	17.7	21	23.3	18

To allow for some "process error" each index was given a CV of 25% within the stock assessment models. The MPD fits were visually checked to make sure that this assumption was consistent with the model fits.

The raw FIS data, including length records, were supplied by Matt Koopman of Fishwell Consulting. These data were used to construct scaled length frequencies that were stratified by zone. Length samples on an individual station were scaled to the catch rate of the station (rather than the catch as not all stations covered the same trawl distance). Scaling was by number with the mean fish weight calculated from the sample weight divided by the number of fish measured. The main issue to deal with was that not all trawl stations that caught ling had been sampled for length (e.g., in the east over the 5 years 20-64% of positive stations were sampled; in the west 26-59% of positive stations were sampled). For these stations, the scaled length frequency and mean fish weight from the associated zone were used (for scaling up to catch rate). The total length frequency for each stock was combined across zones without further weighting.

Model structure

A single-area model with a single time-step was used for both stocks. Ages (1-30+), sex, and maturity were in the partition (although the latter is irrelevant as there were no fisheries that preferentially selected mature fish). The two fisheries (trawl and non-trawl) were assumed to be year-round and mortality was modelled using the Pope approximation to Baranov (CASAL's standard option). Further details of the models are:

Model years	1970-2018	Stock status assessed mid-year 2018
Biomass parameterisation	B_0	Estimated parameter. R_0 is derived.
Recruitment parameterisation	Haist, lognormal prior, sigmaR = 0.7	Also, a moderate penalty on year class strengths (YCS) averaging to 1.
YCS estimated (i.e., recruitment deviations)	East: 1969-1977, 1983-2012 West: 1975-2012	Cohorts 1978-1982 in the east were not well sampled and their YCS were assumed to equal 1.
Steepness	0.75	As used in 2012. A conservative

		value – it may be higher. Fixed.
Maturity	Logistic at age: a_{50} = 5 yr, ato95 = 2 yr	Approximates the length-based curve used in the 2012 assessment. Fixed.
Trawl selectivities	Three blocks in the east: 1970-99, 2000-2006, 2007-2018. Two in the west: 1970-2006, 2007-2018. Double normal at age, same for males and females.	Estimated in the model. Timing of blocks indicated by events and confirmed by data analysis. Right hand limb has a weakly informed prior to encourage a domed shape
Non-trawl selectivities	Logistic at age, same for males and females.	Estimated in the model.
FIS selectivities	Double normal at age, same for males and females	Right hand limb has a weakly informed prior to encourage a domed shape
Growth	Separate male and female von Bertalanffy	Estimated in the model.
Length-weight relationship	a 2.93e-9 b 3.139	Fixed at 2012 assessment values. (cm to tonnes)

MPD methods

Model runs

The western base model and the eastern reference model had the model structure described above and estimated *M*. For the western model the prior on *M* was broad: N(mean=0.2, CV=0.2). The MPD estimate of *M* for the east, when a broad prior was used, was at the upper bound (0.35). This was similar behaviour to what was seen in the 2013 and 2015 assessments and as in those assessments the posterior for *M* from the western assessment was used as a prior for the eastern reference model: N(mean=0.23, CV=0.06). As noted already, the eastern base model was the reference model but with *M* fixed at the point estimate for the western stock (*M*=0.23).

For each stock, there were two sets of MPD models that were run. First, there was a set of "bridging runs" or an "audit trail" where small incremental changes were made from the 2015 base models to get to the 2018 base model (for the western stock) and to the reference model (for the eastern stock).

The second set of runs were sensitivities to the base model (western stock) and the reference model (eastern stock).

Eastern model	**Description**
M=0.2	Reference model with M=0.2
M=0.23 (Base)	Reference model with M=0.23
Est. M (Ref.)	The reference model where M is estimated using the posterior from the western assessment
M=0.28	Reference model with M=0.28
Unf. M	Reference model but a uniform prior on M
Period CPUE	Using the trawl CPUE indices where period effects were estimated and M estimated
Per. M=0.23	As for "Period CPUE" but with M=0.23
Linkall CPUE	Using the trawl CPUE where all vessels were used as linking vessels and M estimated
No FIS	The reference model but with no FIS indices or length frequencies

Western model	Description
M=0.2	Base model with M=0.2
Est. M (Base)	The base model where M is estimated
M=0.28	Base model with M=0.28
Unf. M	Base model but a uniform prior on M
No FIS	The base model but with no FIS indices or length frequencies

Data weighting

The data weights for the composition data were calculated following Francis (2011) using the approach in the 2013 assessment (Cordue 2013) with the exception of the age-length data. In the 2013 assessment it was found that if these were down-weighted fully then the estimation of the growth parameters was compromised. Therefore, these data were weighted as in the 2013 and 2015 assessments (with the number of observations being no more than one in every four fish for which sexed length-age data were available).

MCMC methods

Model runs

For the western assessment only the base model was taken through to MCMC because the estimated stock status was so high that there was no need for sensitivities (they would all show very high stock status just as the base model). The MPD results can be consulted if need be as the MCMC point estimates are very similar to the MPD estimates.

For the eastern assessment five models were taken through to MCMC: the reference model, reference with M=0.23 (base), Period CPUE with M=0.23, reference with M=0.2, and the linkall CPUE (with M estimated). The first three models listed were offered to the second SERAG meeting as potential base models for the eastern assessment.

MCMC chains and diagnostics

For the western base model and the eastern reference model, ten chains were run, a burn-in was used and the remaining parts of the chains were combined and used to produce the main estimates and plots (see Appendix C). For runs where M was not estimated, six chains were used rather than ten (the partial confounding of B_0 and M means it is necessary to have more/longer chains when M is estimated).

The primary diagnostic, to confirm that enough chains had been run over a sufficient length, was to compare the posterior distributions of the estimated parameters between the first half and the second half of all chains combined. In particular, a standardised median was calculated for each parameter for each half of all chains combined (after burn-in). This was the median over one of the halves divided by the median over both halves. The standardised medians were plotted for all parameters to check that they were within 08–1.2 for all parameters. This was also done for spawning stock biomass over the whole timeframe (but the differences were much less than 20%). A final check was a visual comparison of the histograms for the first half and second half (all chains combined) for B_0, current stock status, and M (if estimated). See Appendix C for full diagnostics for the western base model, and three models for the eastern assessment (base, reference, and period CPUE with M=0.23).

For the purposes of calculating RBC, long-term yield and doing constant catch projections a random sample of 3000 was taken from the stored posterior samples for the given model.

Estimation of RBC and long-term yield

The generic control rule was applied to each of the 3000 posterior samples assuming that the exploitation rates of the trawl to non-trawl fisheries were maintained in a ratio of 1.4 to 1 in the east and 1.1 to 1 in the west (from the MPD estimates in 2010–2013; ignoring the ratios since then which are different given the eastern trip limits and the shift of effort from east to west).

F_{48} was determined by scaling exploitation rates (up or down) until the corresponding long-term equilibrium SSB, under deterministic recruitment, was equal to 48% B_0 (i.e., B_{48}). The estimate of RBC was taken to be the catch in 2019 associated with F_{target} where:

$$
\begin{aligned}
F_{target} &= F_{48} && \text{for } B_{current} \geq B_{35} \\
&= F_{48}\,(B_{current} - 0.2)/0.15 && \text{for } B_{20} < B_{current} < B_{35} \\
&= 0 && \text{for } B_{current} \leq B_{20}.
\end{aligned}
$$

The long-term yield was estimated as the catch associated with F_{48} when the stock reached deterministic equilibrium.

For each sample, deterministic projections were run at different levels of scaled exploitation rates to determine F_{48} and the associated catches, in 2019, and at equilibrium (by linear interpolation). The control rule was then applied to determine the RBC estimate for each member of the chain (and hence to an RBC posterior distribution).

Projections and risk assessment

For the western base model short-term projections (to 2028) were performed for constant catch strategies at 600 t to 1000 t per year (assuming 60% of the catch was trawl as in recent years).

For the eastern base model, short-term (to 2028) and long-term projections (to 2050) were performed for constant catch strategies at zero catch and from 300 t to 650 t per year (assuming 68% of the catch is trawl which is the normal average just prior to the imposition of eastern trip limits).

For both stocks, full stochastic projections were used where year class strengths from 2013 onwards were randomly sampled from all estimated YCS.

Eight performance indicators were calculated for each constant catch strategy:

- $E(B_{2021}/B_0)$: mean stock status in 2021
- $E(B_{2028}/B_0)$: mean stock status in 2028
- $P(B_{2021} < 0.2)$: probability that SSB in 2021 is less than 20% B_0
- $P(B_{2028} < 0.2)$: probability that SSB in 2028 is less than 20% B_0
- $P(B_{2021} < 0.3)$: probability that SSB in 2021 is less than 30% B_0
- $P(B_{2028} < 0.3)$: probability that SSB in 2028 is less than 30% B_0
- $P(B_{2021} \geq 0.48)$: probability that SSB in 2021 is at least 48% B_0
- $P(B_{2028} \geq 0.48)$: probability that SSB in 2028 is at least 48% B_0

Also, for the eastern MCMC models, the year in which there was at least a 50% probability of SSB exceeding 48% B_0 was determined for each constant catch strategy. To put the timeframe required to rebuild to the target in context, the mean generation time for ling was calculated being the average age of a mature fish in an unexploited population (under the base maturity assumption for different values of M):

M	**0.20**	**0.21**	**0.22**	**0.23**	**0.24**	**0.25**
Generation time (years)	9.7	9.4	9.2	9.0	8.8	8.6

Results

Audit trail

The eastern MPD estimates are very consistent with those in the 2015 stock assessment (Table 1, Figure 5). The addition of some weak priors on the trawl selectivities was the only difference between the base MPD model in 2015 (MPD15) and the MPD model for the base MCMC run (Final15). The MPD results are almost identical (Table 1). The revision and extension of the catch history to 2018 made little difference, as did the new CPUE time series and the inclusion of the FIS indices (Table 1, Figure 5). As in the 2015 assessment it is high and low values of natural mortality (M) that make the biggest difference to stock status (Table 1, Figure 5).

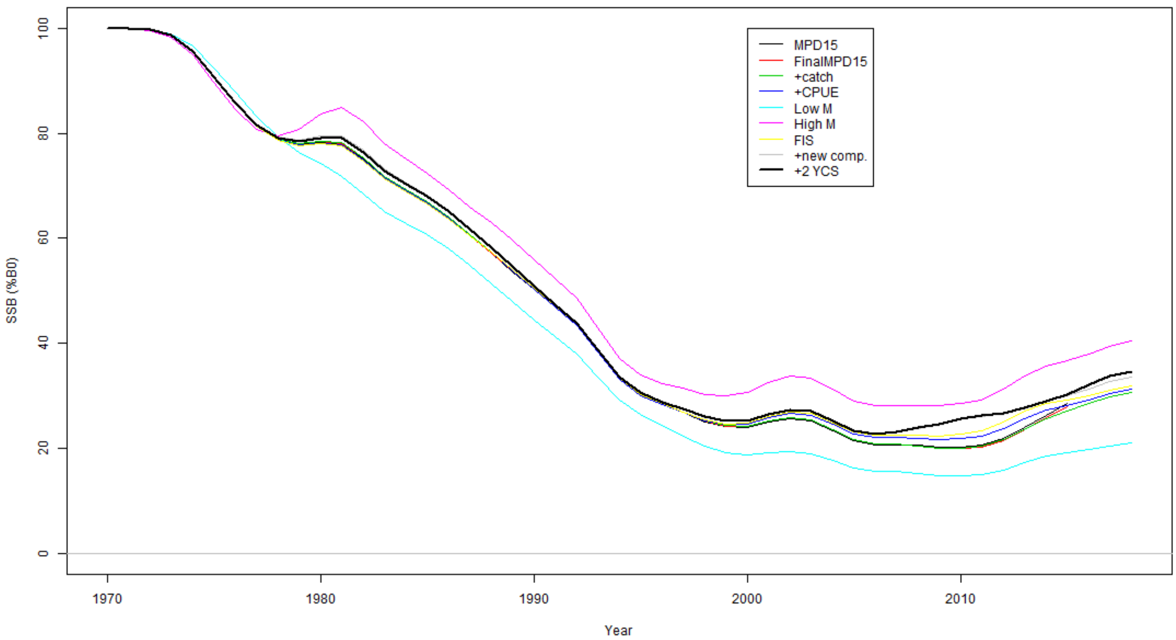

Figure 5: Preliminary MPD estimates for the eastern stock showing estimated stock status trajectories for the audit trail runs: the 2015 base MPD model (MPD15), the MPD estimate for the 2015 base MCMC model (Final15), the revision and extension of the catch history to 2018 (+catch), the inclusion of the new CPUE time series (+CPUE), the previous run with low and high M, the inclusion of the FIS indices (+FIS), the inclusion of the new composition data (+new comp.), and the estimation of two more YCS (+2 YCS).

The western MPD estimates are also consistent with the 2015 results when the catch is revised and extended and the new CPUE indices are used (Table 2, Figure 6). The inclusion of the FIS indices increases the estimates of stock status somewhat but as in the east it the low and high values of M which have the most impact (Table 2, Figure 6). The estimation of two more YCS (2011 and 2012) than estimated in the 2015 assessment gives a large increase in estimated stock status (Table 2, Figure 6). The estimation of these YCS is justified because they are observed in the composition data that was added to the assessment. Also, they deliver a much improved fit to the CPUE indices (Figure 7) and also to the composition data (e.g., the 2016 FIS length frequency – see Figure 8).

Table 1: Eastern stock: preliminary MPD estimates of natural mortality (M), virgin female spawning biomass (B_0), female spawning biomass in 2015 (B_{2015}) and 2018 (B_{2018}), and stock status in 2015 (ss_{15} = B_{2015}/B_0) and 2018 (ss_{15} = B_{2015}/B_0). Results are shown for the audit trail runs (see Figure 5). The final run (+ 2 YCS) is the 2018 reference model.

	M	B_0 (t)	B_{2015} (t)	B_{2018} (t)	ss_{2015} (% B_0)	ss_{2018} (% B_0)
Mpd15	0.24	5420	1540	-	29	-
Final15	0.24	5380	1510	-	28	-
+ catch	0.24	5380	1460	1650	27	31
+ CPUE	0.24	5390	1520	1680	28	31
Low M	0.20	6910	1320	1450	19	21
High M	0.28	4720	1730	1910	37	40
+ FIS	0.24	5390	1570	1720	29	32
+ new comp.	0.25	5390	1620	1810	30	34
+ 2 YCS	0.25	5400	1630	1870	30	35

Table 2: Western stock: preliminary MPD estimates of natural mortality (M), virgin female spawning biomass (B_0), female spawning biomass in 2015 (B_{2015}) and 2018 (B_{2018}), and stock status in 2015 (ss_{15} = B_{2015}/B_0) and 2018 (ss_{15} = B_{2015}/B_0). Results are shown for the audit trail runs (see Figure 6). The final run (+ 2 YCS) is the 2018 base model.

	M	B_0 (t)	B_{2015} (t)	B_{2018} (t)	ss_{2015} (% B_0)	ss_{2018} (% B_0)
Mpd15	0.22	5110	3630	-	71	-
+ catch	0.22	5110	3570	3450	70	68
+ CPUE	0.22	5140	3760	3750	73	73
Low M	0.20	5020	3230	3240	64	65
High M	0.28	6980	6510	6420	93	92
+ FIS	0.23	5310	4130	4160	78	78
+ new comp.	0.23	5060	3760	3720	74	73
+ 2 YCS	0.23	5410	3810	4730	71	87

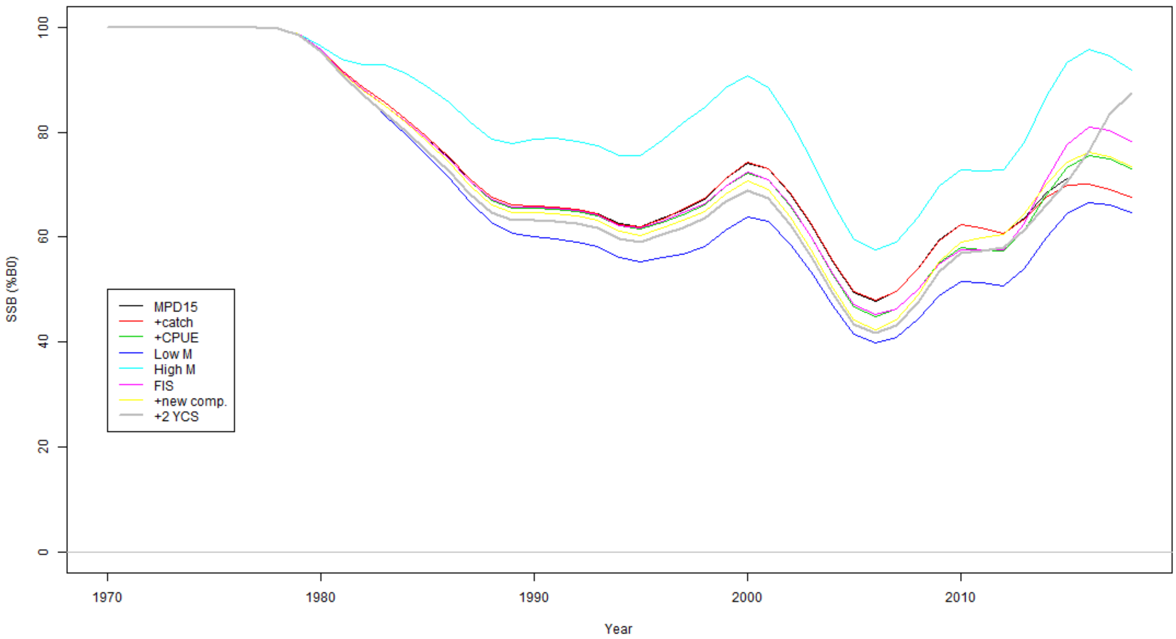

Figure 6: Preliminary MPD estimates for the western stock showing estimated stock status trajectories for the audit trail runs: the 2015 base MPD model (MPD15), the revision and extension of the catch history to 2018 (+catch), the inclusion of the new CPUE time series (+CPUE), the previous run with low and high M, the inclusion of the FIS indices (+FIS), the inclusion of the new composition data (+new comp.), and the estimation of two more YCS (+2 YCS).

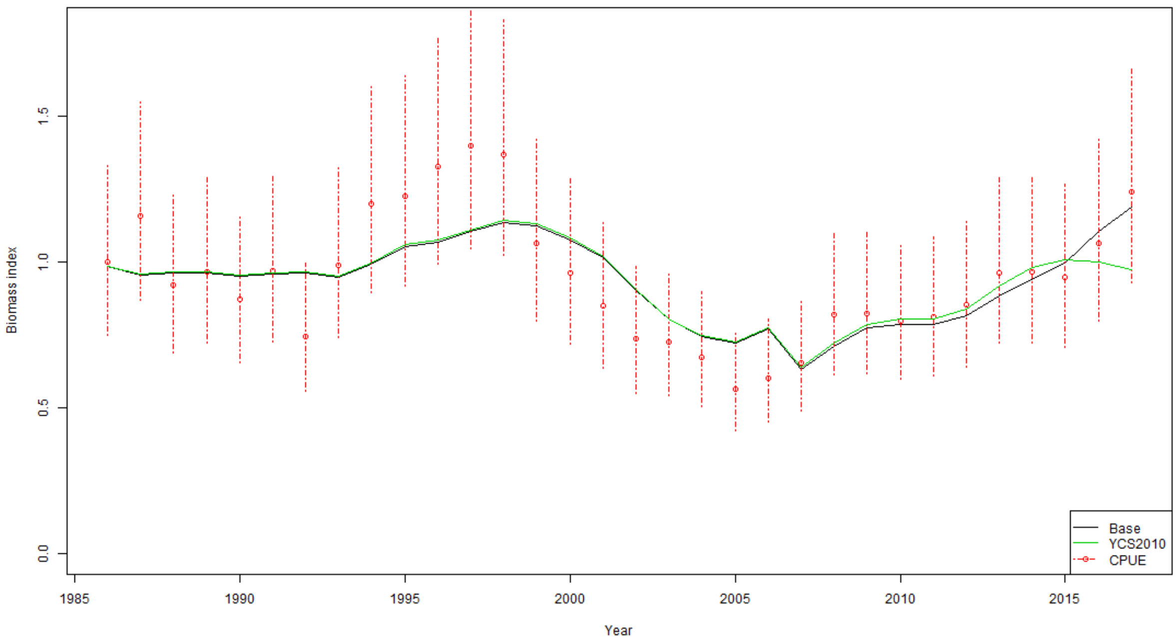

Figure 7: Western stock: MPD fit to the trawl CPUE indices for the base model (YCS estimated to 2012) and the model which only estimates YCS to 2010.

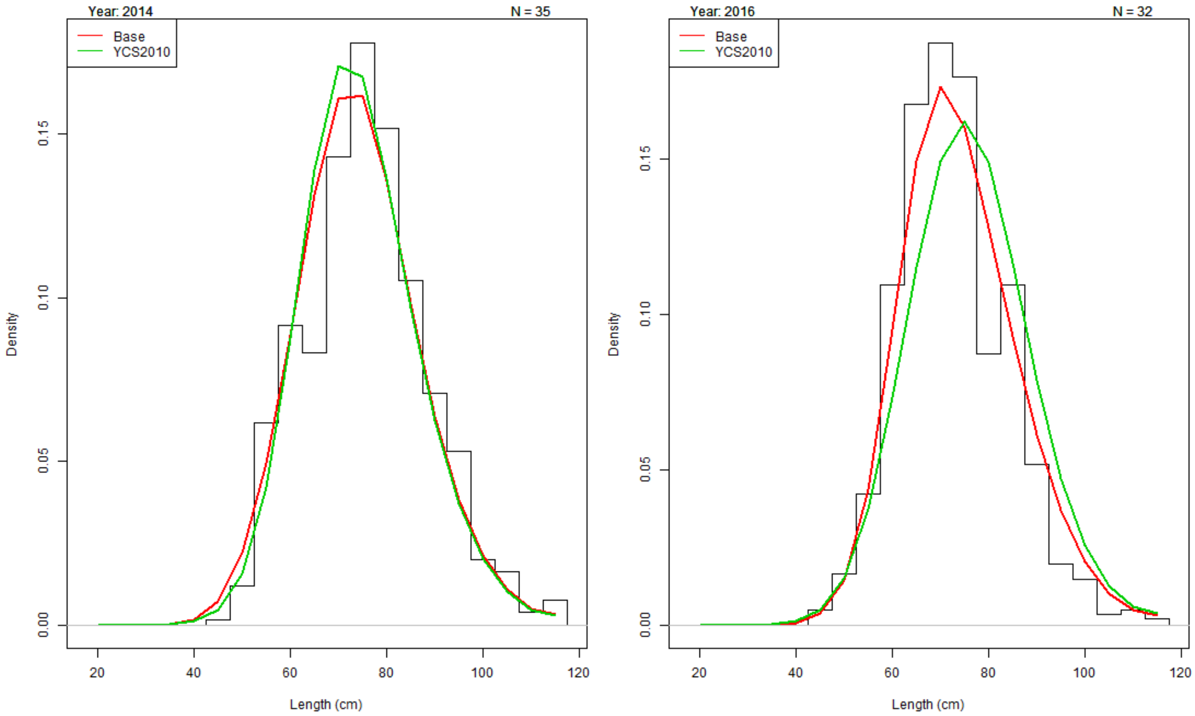

Figure 8: Western stock: MPD fit to the recent FIS length frequencies for the base model (YCS estimated to 2012) and the model which only estimates YCS to 2010.

MPD estimates

In this section the results are given for the 2018 MPD models.

Eastern stock

The MPD estimates of B_0 and stock status for the eastern stock depend very much on whether M is estimated and, if not, the value at which M is fixed (Table 3, Figures 9, 10). If M is estimated with a uniform prior ("Unf. M") the estimate is at the upper bound of 0.35 and the subsequent stock status is 61% B_0 (Table 3). Both estimates are very unrealistic.

There is also some sensitivity to which CPUE time series is used. The "Period CPUE" time series increases steeply in 2016 and 2017 and this is reflected in the estimates of stock status (Table 3, Figure 10). The Linkall CPUE shows little increase in the recent period and this is reflected in lower estimated stock status (Table 3, Figure 10).

Irrespective of the estimated or fixed value of M, the fit to the base CPUE time series is always excellent (Figure 11). The Period CPUE is not fitted nearly as well with the large increase in 2016 and 2017 not being matched by the model (Figure 12). The Linkall CPUE series has an excellent fit (Figure 13).

Table 3: Eastern stock: MPD estimates of natural mortality (M), virgin female spawning biomass (B_0), female spawning biomass in 2018 (B_{2018}), and stock status in 2018 ($ss_{18} = B_{2018}/B_0$). Results are shown for the final MPD runs. Sensitivities are to the reference model. M=0.23 was ultimately chosen as the base model.

	M	**B_0 (t)**	**B_{2018} (t)**	**ss_{2018} (%B_0)**
M=0.2	0.20	7020	1740	25
M=0.23 (Base)	0.23	5860	1820	31
Est. M (Ref.)	**0.25**	**5400**	**1870**	**35**
M=0.28	0.28	4780	2040	43
Unf. M	0.35	4510	2730	61
Period CPUE	0.25	5590	2330	42
Per. M=0.23	0.23	6070	2260	37
Linkall CPUE	0.25	5260	1440	27
No FIS	0.25	5450	1930	35

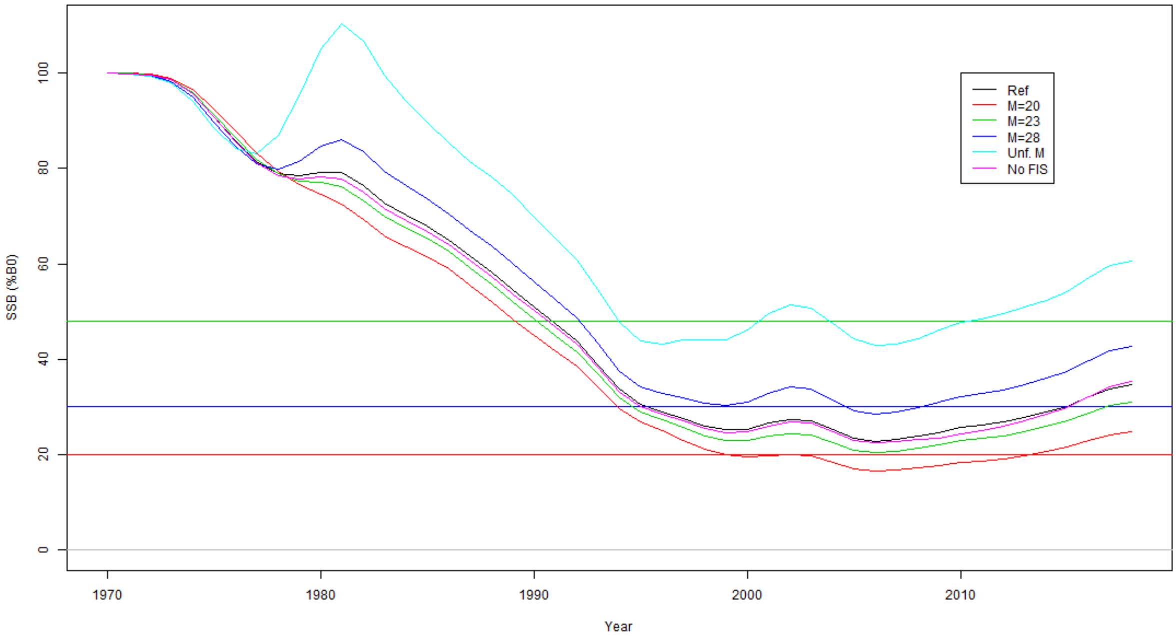

Figure 9: Eastern stock: MPD estimates of spawning stock biomass trajectory for each of the final MPD runs which used the base CPUE. SSB is presented as %B_0. Horizontal lines are marked at 20%, 30%, and 48% B_0.

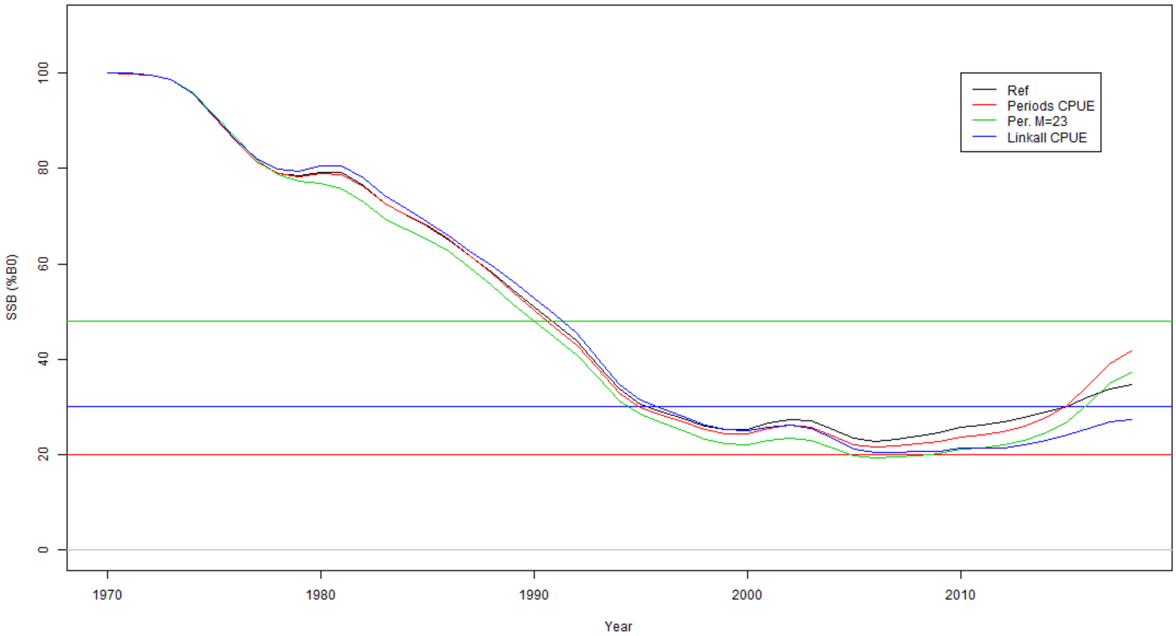

Figure 10: Eastern stock: MPD estimates of spawning stock biomass trajectory for the reference model and each of the final MPD runs which did not use the base CPUE. SSB is presented as %B_0. Horizontal lines are marked at 20%, 30%, and 48% B_0.

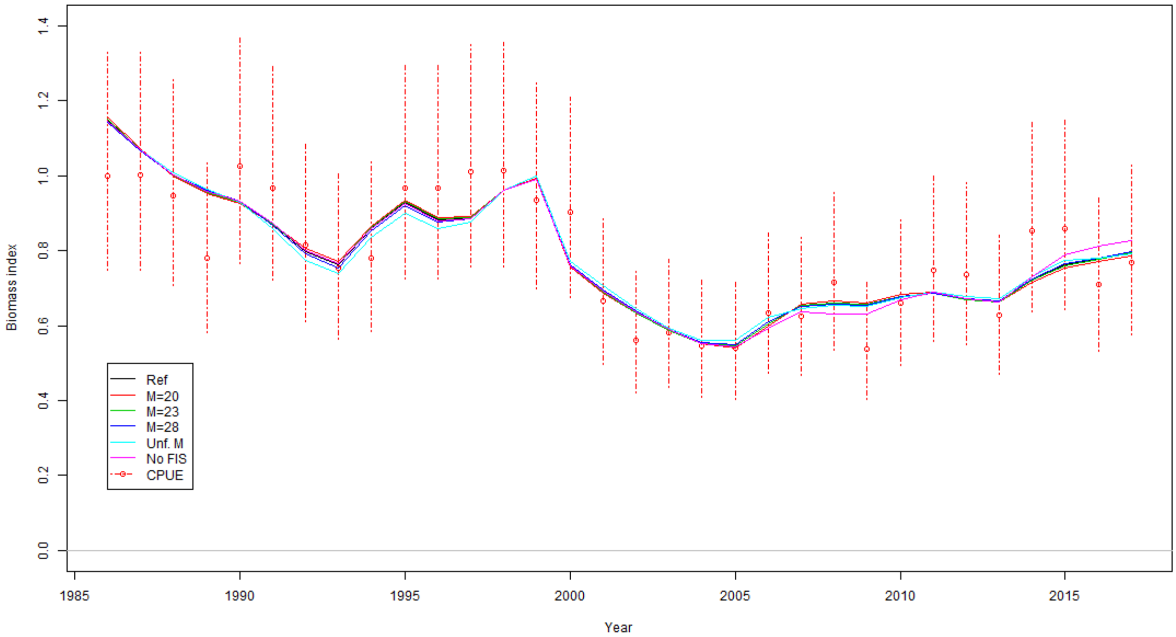

Figure 11: Eastern stock: MPD fit to the base trawl CPUE indices for the final MPD runs that used the time series.

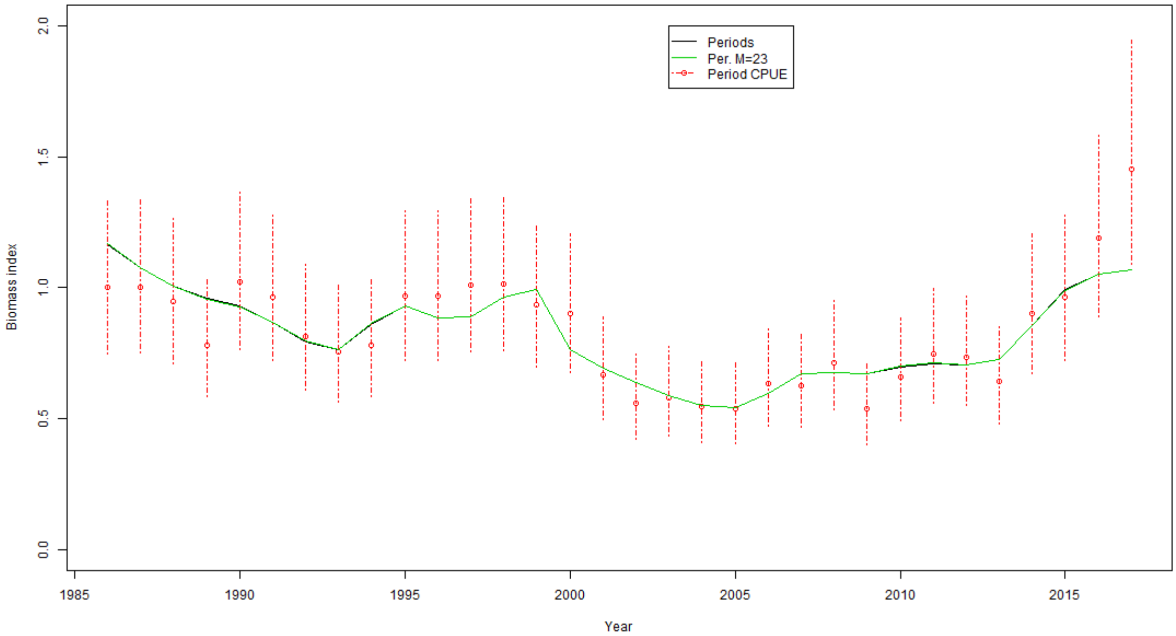

Figure 12: Eastern stock: MPD fit to the period based trawl CPUE indices for the final MPD runs that used the time series.

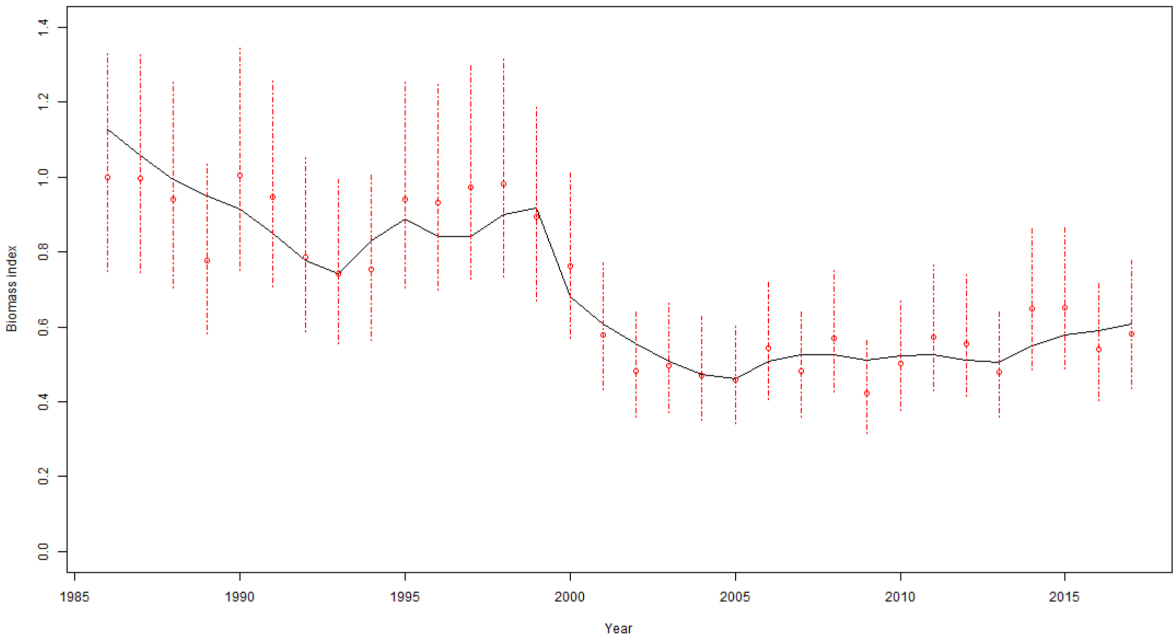

Figure 13: Eastern stock: MPD fit to the all-vessels-linked trawl CPUE indices for the final MPD run that used that time series.

The fit to the FIS biomass indices is almost identical for each of the models irrespective of the estimated or fixed value of M (Figure 14). The model has plenty of room to adjust other parameters to achieve a comparable fit to biomass indices and composition data (e.g., B_0 and selectivities). The likelihood profile for M when fitted with a uniform prior shows that the only opposition to very high values of M is from the length frequency data from the trawl fishery (Figure 15). The relative weightings of the data would therefore be influential on the estimate of M.

The likelihood profile for B_0 in the reference model (where M is estimated with a tight prior) shows that the main opposition to low values of B_0 is from priors and penalties (Figure 16). This is because at low values of B_0 high values of M are estimated (Figure 17) and this invokes a penalty on the prior for M. When M is fixed at 0.23 the likelihood profile shows that low values of B_0 are opposed by the conditional age-at-length data (Figure 18). This is a legitimate signal as too little biomass would result in truncation of the age structure which is not present in the observed age data (especially the non-trawl fishery which has a logistic selectivity).

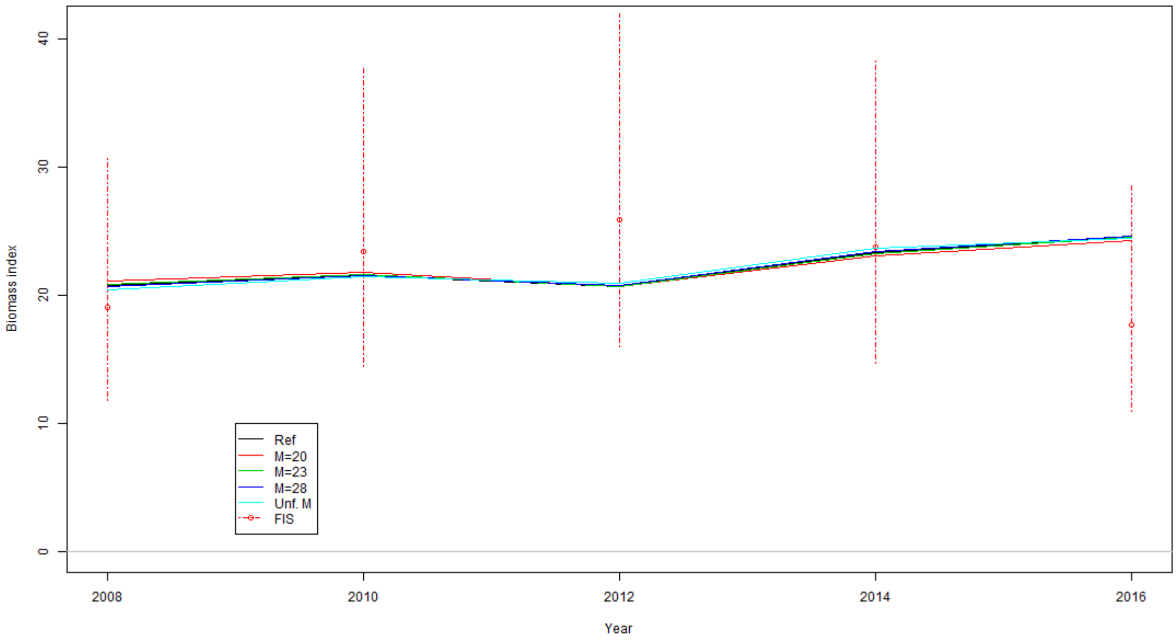

Figure 14: Eastern stock: MPD fit to the FIS indices for the final MPD runs that used the base trawl CPUE indices.

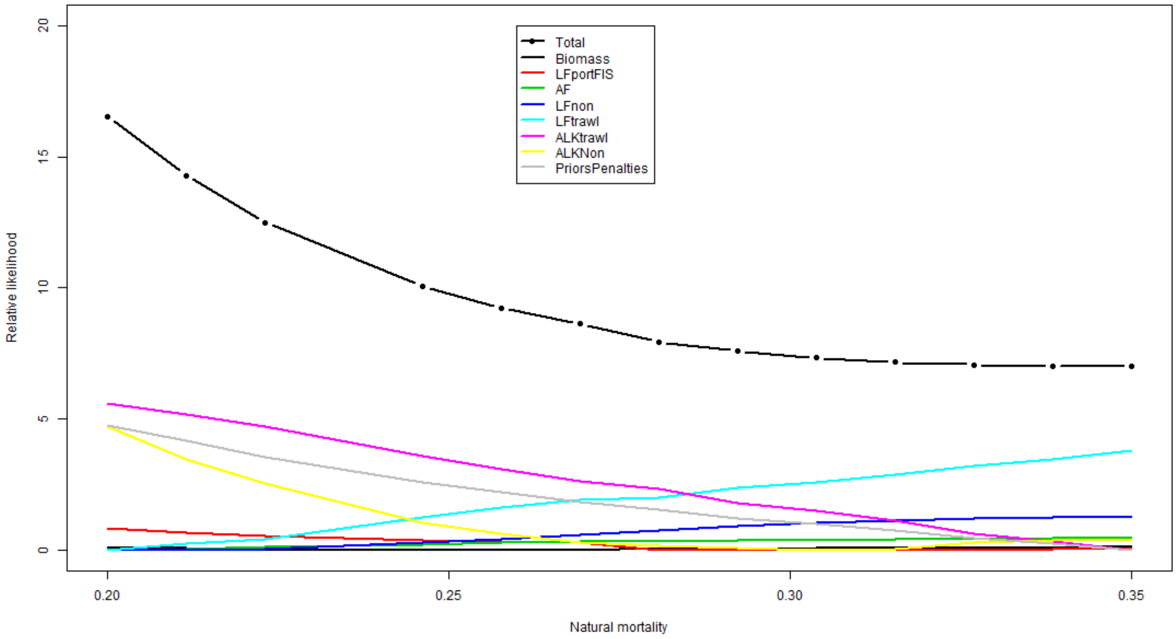

Figure 15: Eastern stock: Likelihood profile on M for the model with a uniform prior on M showing the contribution to the total likelihood for the different data sets, priors, and penalties for fixed values of M from 0.20 to 0.35. (Biomass = biomass indices, AF = age frequencies, LF = length frequencies, ALK = age-length data, non = non-trawl.)

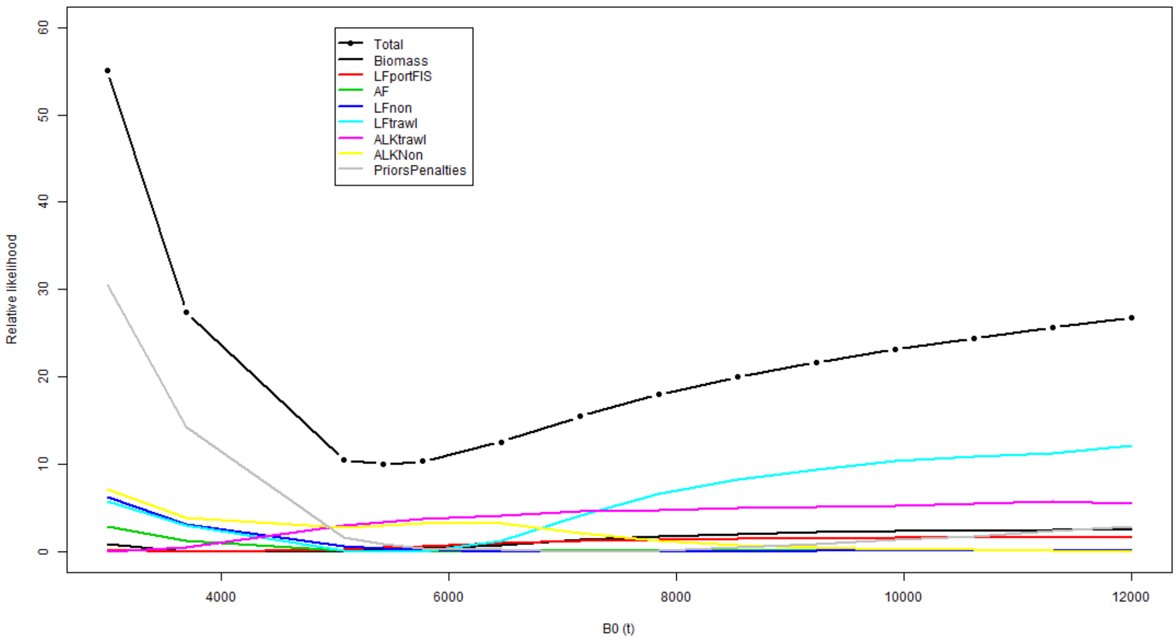

Figure 16: Eastern stock: Likelihood profile on B_0 for the reference model showing the contribution to the total likelihood for the different data sets, priors, and penalties for fixed values of B_0. (Biomass = biomass indices, AF = age frequencies, LF = length frequencies, ALK = age-length data, non = non-trawl.)

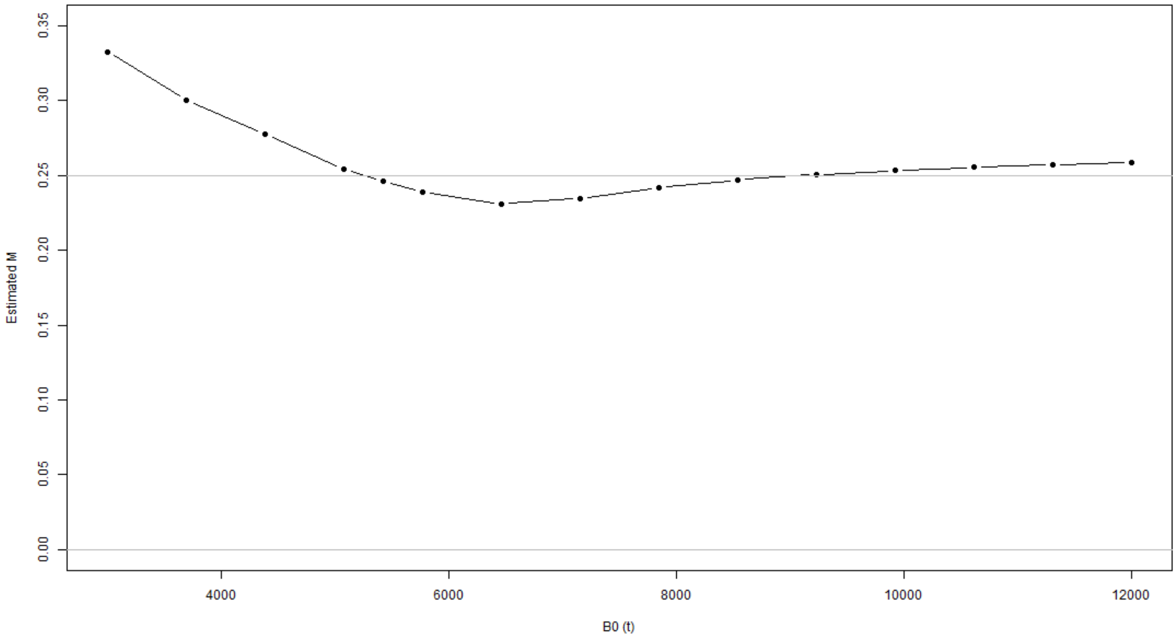

Figure 17: Eastern stock: MPD estimates of M for fixed values of B_0 (from the likelihood profile on B_0). The horizontal line is at M=0.25 the MPD estimate of M in the reference model.

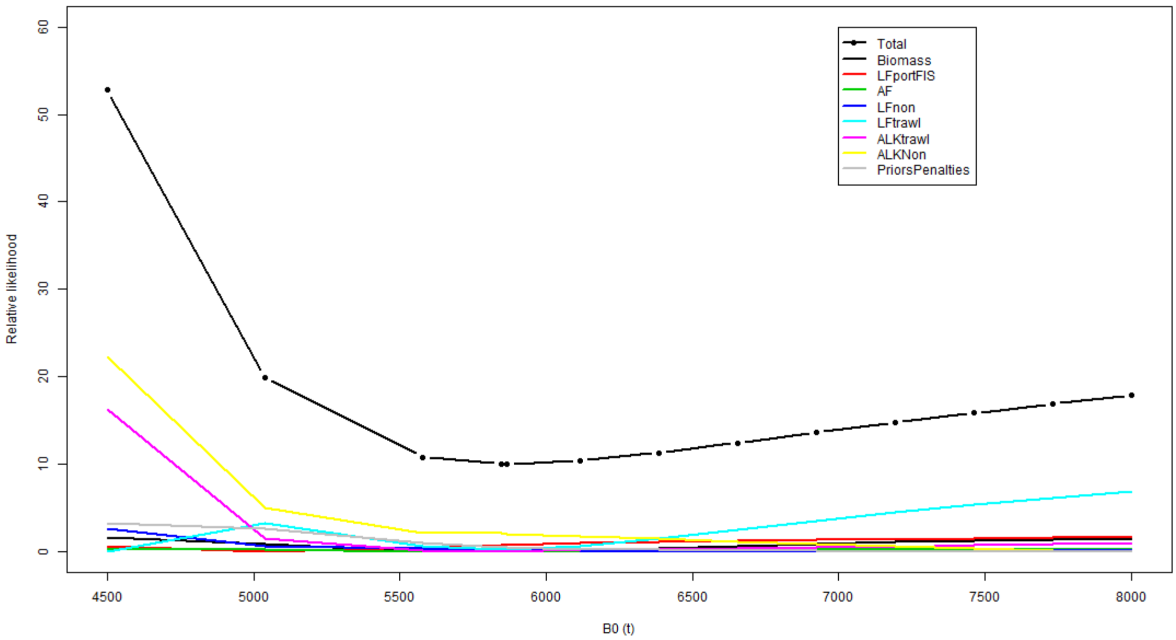

Figure 18: Eastern stock: Likelihood profile on B_0 (when M is fixed at 0.23) showing the contribution to the total likelihood for the different data sets, priors, and penalties for fixed values of B_0. (Biomass = biomass indices, AF = age frequencies, LF = length frequencies, ALK = age-length data, non = non-trawl.)

The growth estimates are very similar across model runs (Figure 19). The estimated selectivities for the FIS and the commercial fisheries are driven by the associated fixed or estimated value of M (Figures 20-25). The estimated YCS also show a pattern with M for the models that fitted the base CPUE (Figure 26). For the models that fitted alternative CPUE time series, the Linkall CPUE model has very similar YCS estimates to the reference model but the Period CPUE model, of course, estimates higher recent YCS to try to fit the increasing CPUE in 2016 and 2017 (Figure 27).

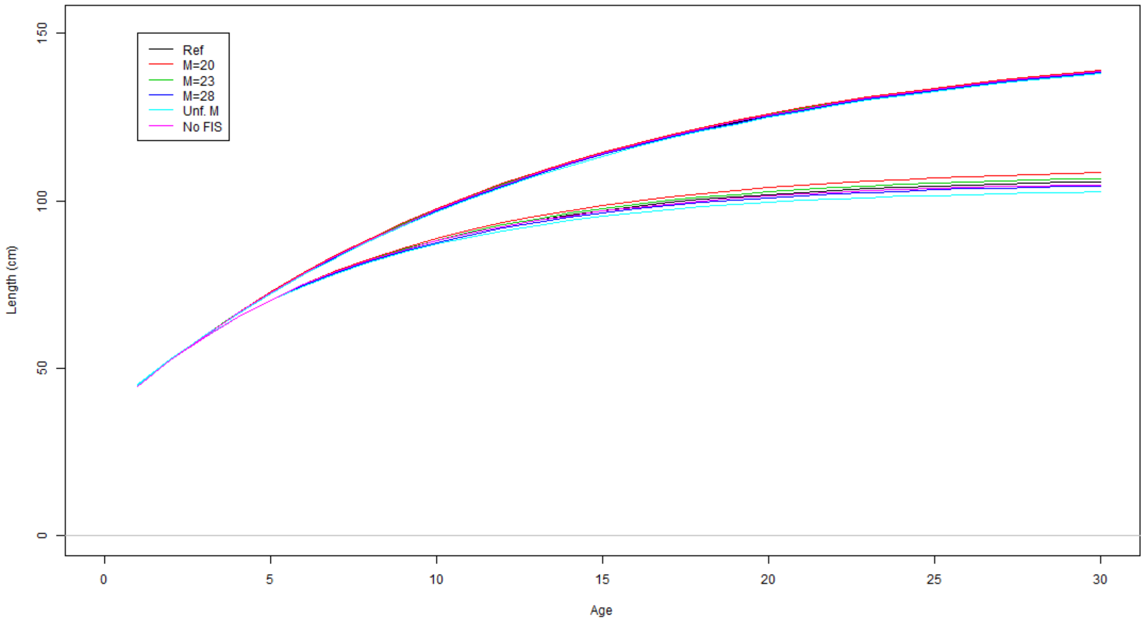

Figure 19: Eastern stock: MPD estimates of length at age for male (bottom group) and female (top group) ling for each of the final MPD runs which used the base CPUE.

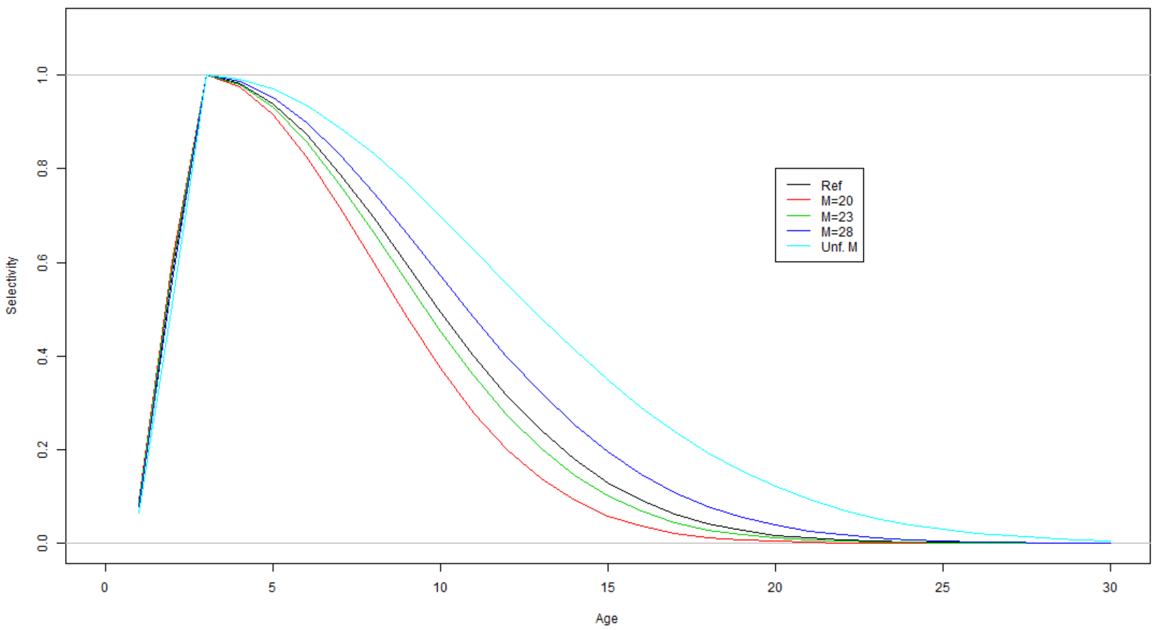

Figure 20: Eastern stock: MPD estimates of the selectivity for the FIS for each of the final MPD runs which used the base CPUE.

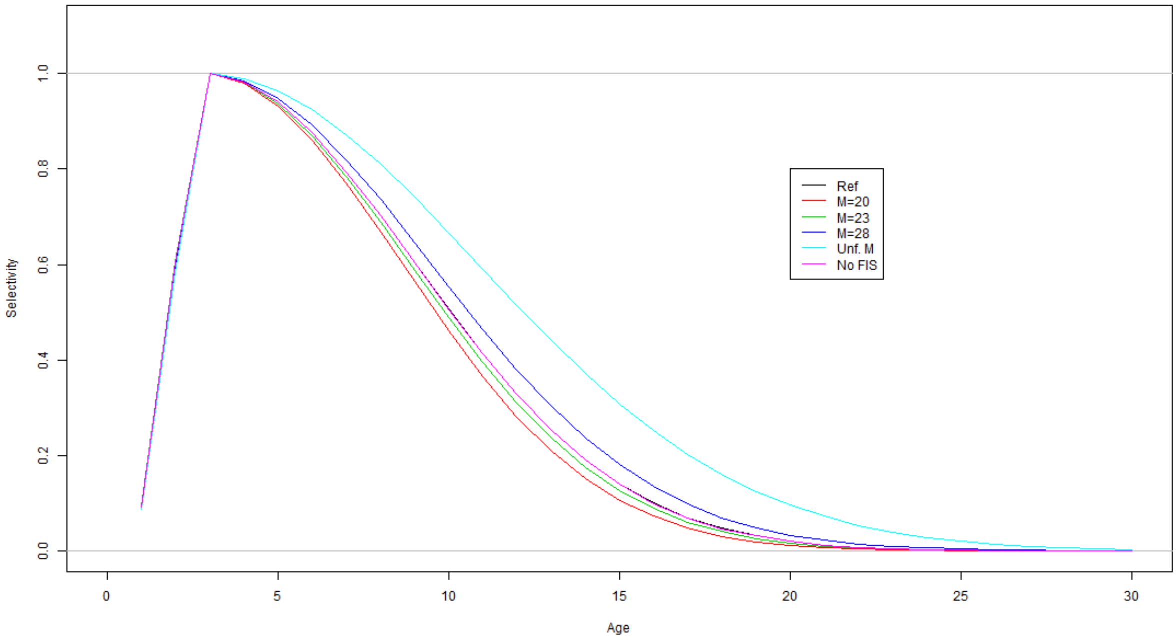

Figure 21: Eastern stock: MPD estimates of the selectivity for the trawl fishery in the first time block for each of the final MPD runs which used the base CPUE.

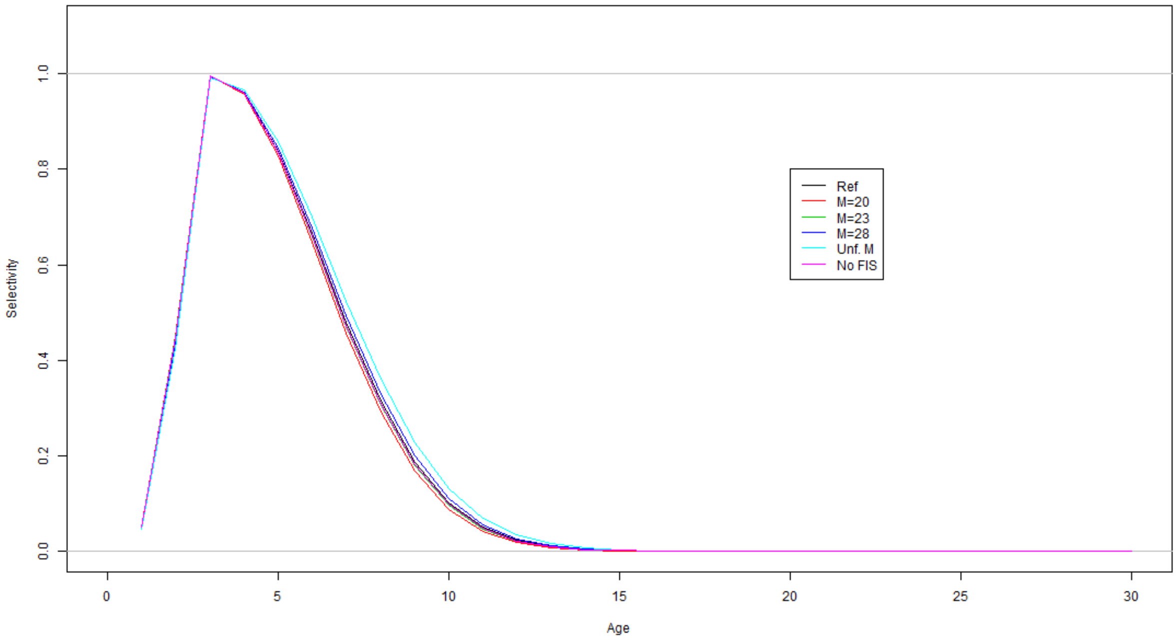

Figure 22: Eastern stock: MPD estimates of the selectivity for the trawl fishery in the second time block for each of the final MPD runs which used the base CPUE.

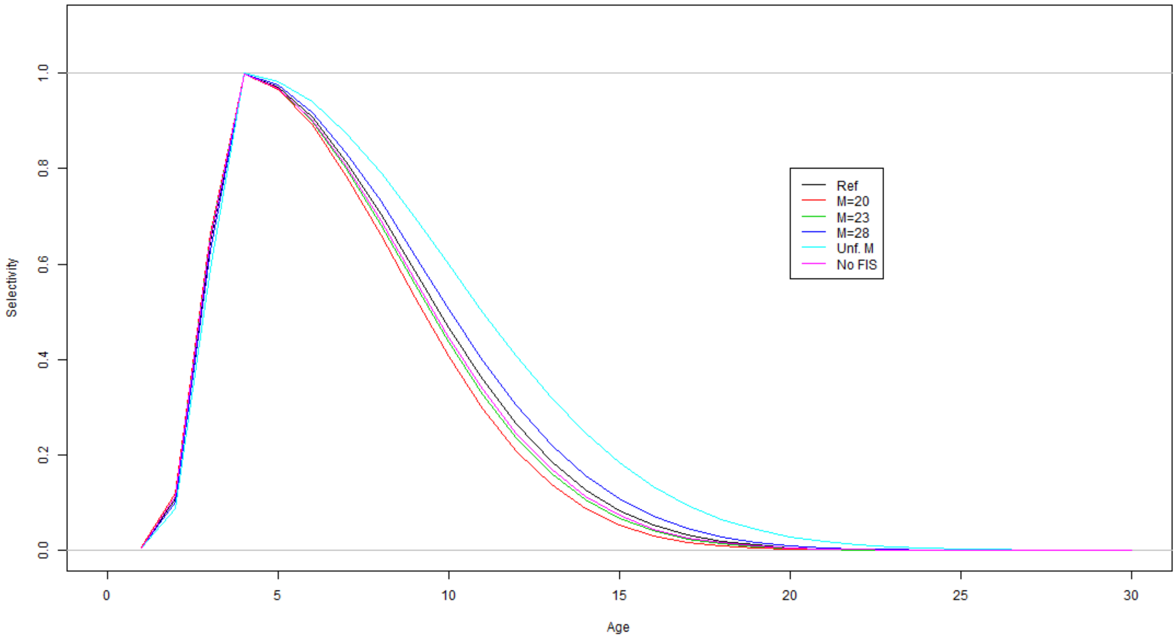

Figure 23: Eastern stock: MPD estimates of the selectivity for the trawl fishery in the third time block for each of the final MPD runs which used the base CPUE.

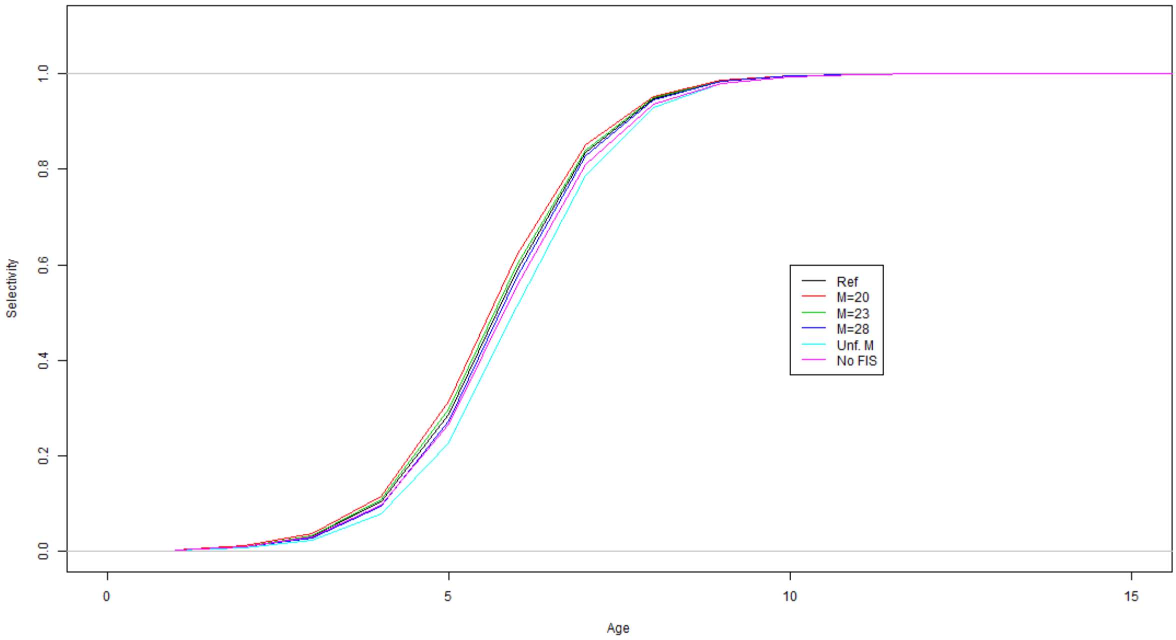

Figure 24: Eastern stock: MPD estimates of the selectivity for the non-trawl fishery sampled at sea for each of the final MPD runs which used the base CPUE.

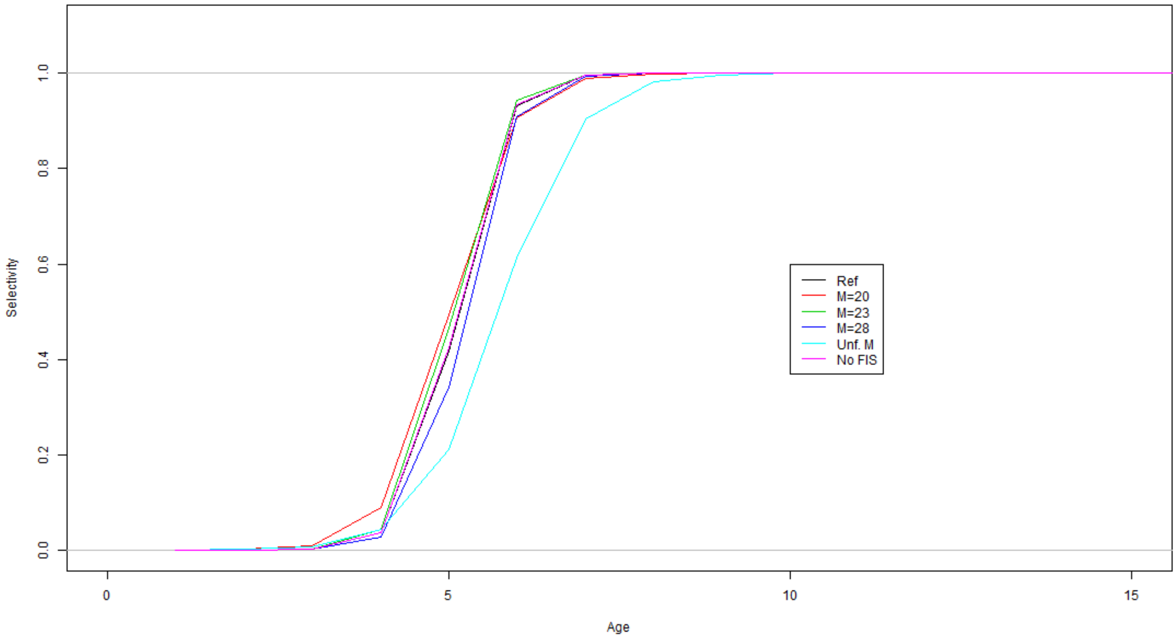

Figure 25: Eastern stock: MPD estimates of the selectivity for the non-trawl fishery sampled at port for each of the final MPD runs which used the base CPUE.

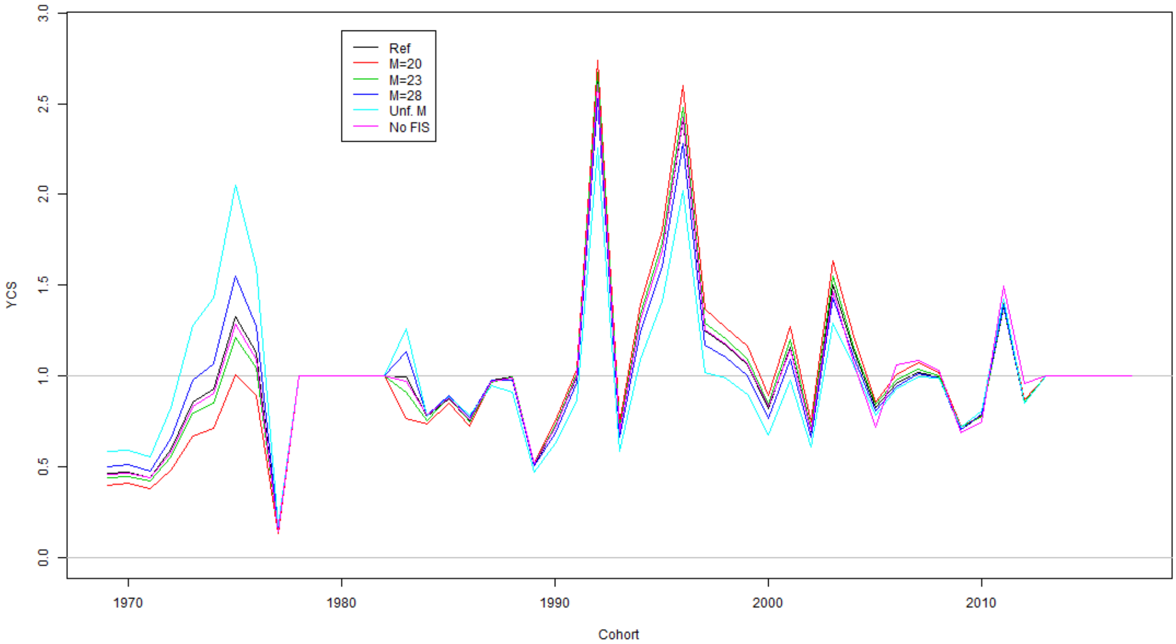

Figure 26: Eastern stock: MPD estimates of YCS for each of the final MPD runs which used the base CPUE.

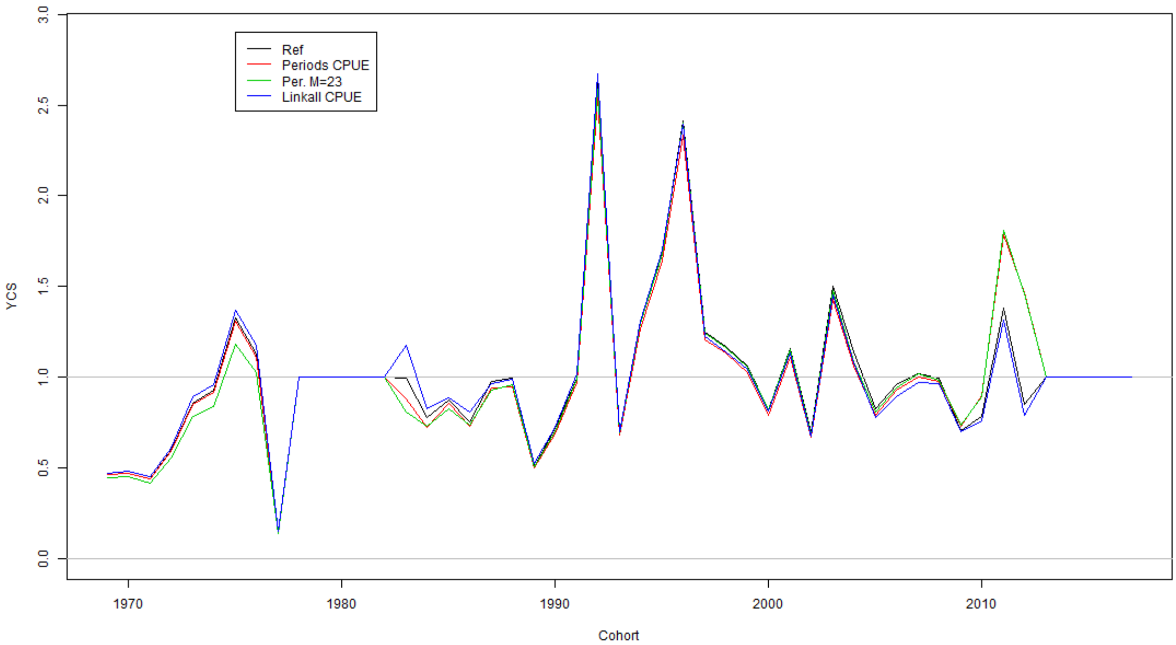

Figure 27: Eastern stock: MPD estimates of YCS for the reference model and each of the final MPD runs which did not use the base CPUE.

Estimated exploitation rates are higher for the trawl fishery than the non-trawl fishery over the whole time period (Figure 28). The average ratio of trawl exploitation rate to non-trawl exploitation rate for the period 2010-2013 is 1.4 (Figure 29). This ratio was used in constant catch projections to maintain the relative exploitation rates of the fisheries within the model. The period was chosen as it was just before the imposition of a series of changeable management actions.

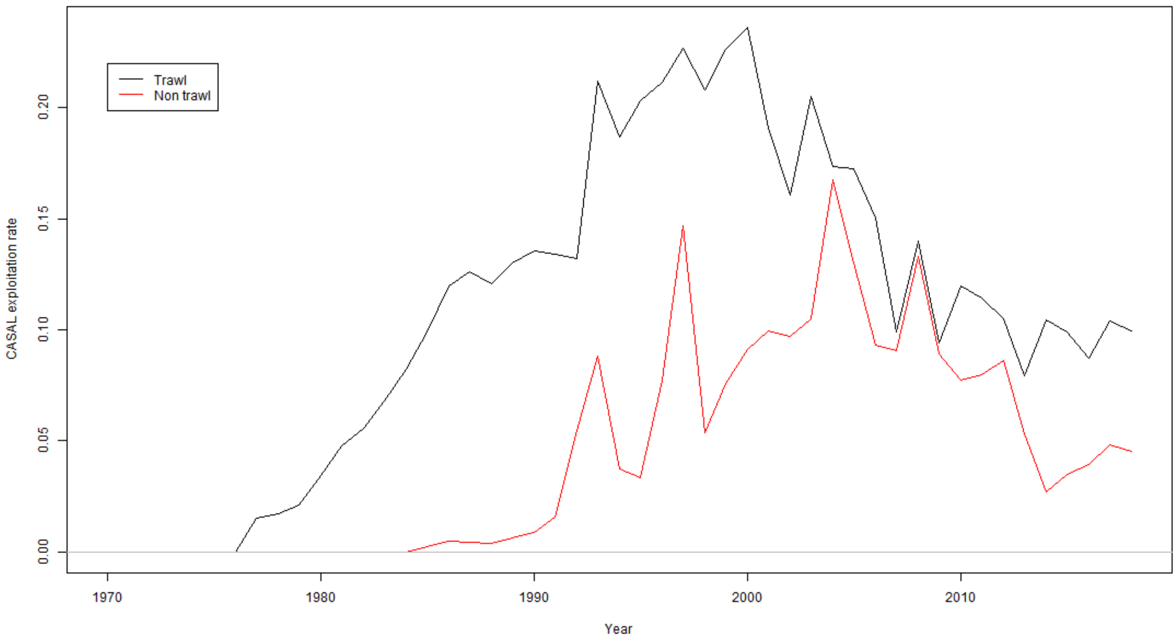

Figure 28: Eastern stock: MPD estimates of annual CASAL exploitation rates for the trawl and non-trawl fisheries in the reference model.

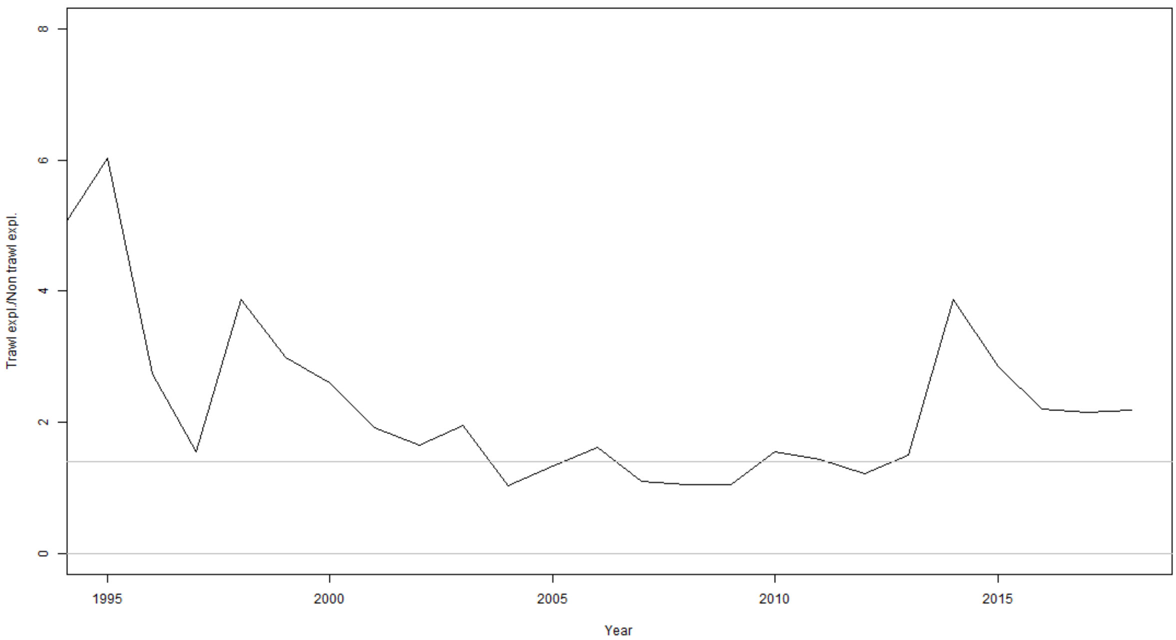

Figure 29: Eastern stock: MPD estimates of the trawl exploitation rate divided by the non-trawl exploitation rate in the reference model. The average ratio for 2010-2013 inclusive is marked as a horizontal line at 1.4.

Western stock

The MPD estimates of B_0 and stock status for the western stock are not particularly sensitive to whether M is estimated or fixed at higher or lower values (Table 4, Figure 30). The estimate of M is very similar for the base model (with a N(mean=0.2,CV=20%) prior) and the model with a uniform prior on M (Table 4). All models use the same trawl CPUE series which shows a strong increasing trend which is reflected in the estimates of stock status (Table 4, Figure 30). The fit to the trawl CPUE time series is very similar for all models with a poor residual pattern from 1993 to 2006 (Figure 31). The fit to the FIS biomass indices is adequate (Figure 32).

Table 4: Western stock: MPD estimates of natural mortality (M), virgin female spawning biomass (B_0), female spawning biomass in 2018 (B_{2018}), and stock status in 2018 ($ss_{18} = B_{2018}/B_0$). Results are shown for the final MPD runs (see Figure 30).

	M	B_0 (t)	B_{2018} (t)	ss_{2018} (% B_0)
M=0.2	0.20	5270	3910	74
Est. M (Base)	**0.23**	**5410**	**4730**	**87**
M=0.28	0.28	6970	7520	108
Unf. M	0.24	5560	5090	92
No FIS	0.23	5110	4130	81

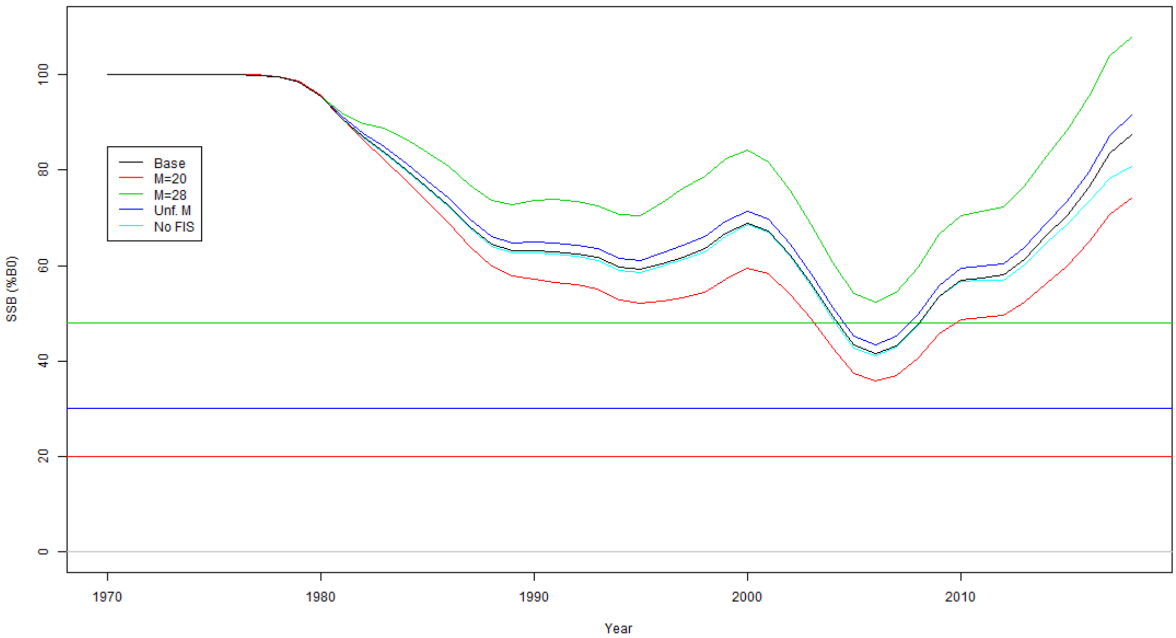

Figure 30: Western stock: MPD estimates of spawning stock biomass trajectory for each of the final MPD runs. SSB is presented as % B_0. Horizontal lines are marked at 20%, 30%, and 48% B_0.

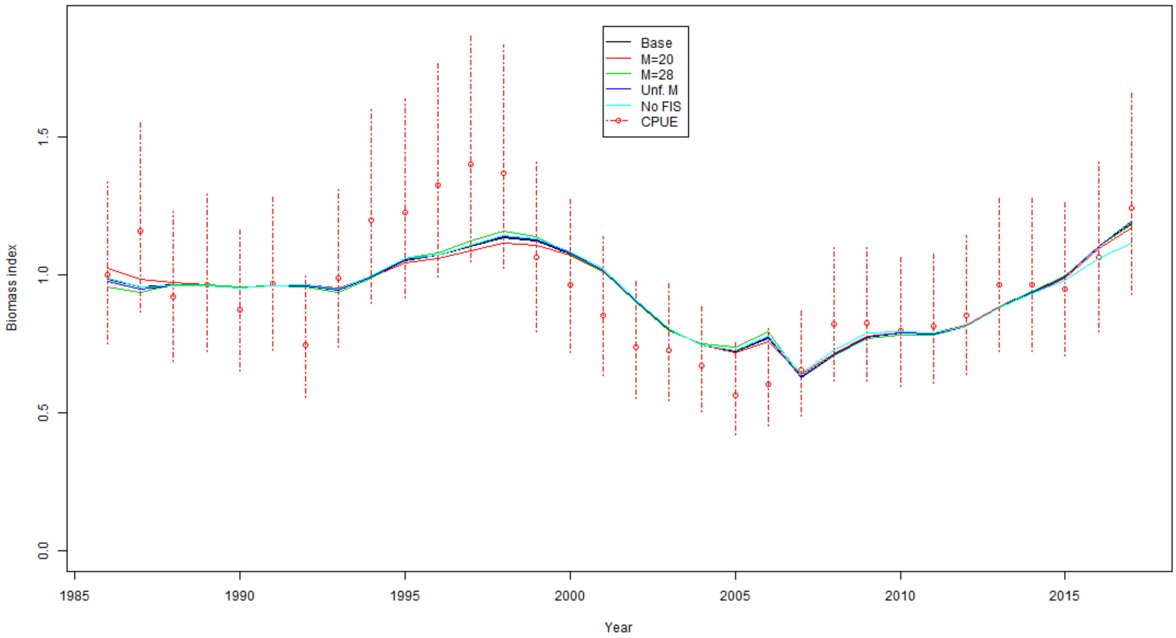

Figure 31: Western stock: MPD fit to the trawl CPUE indices for all of the final MPD runs.

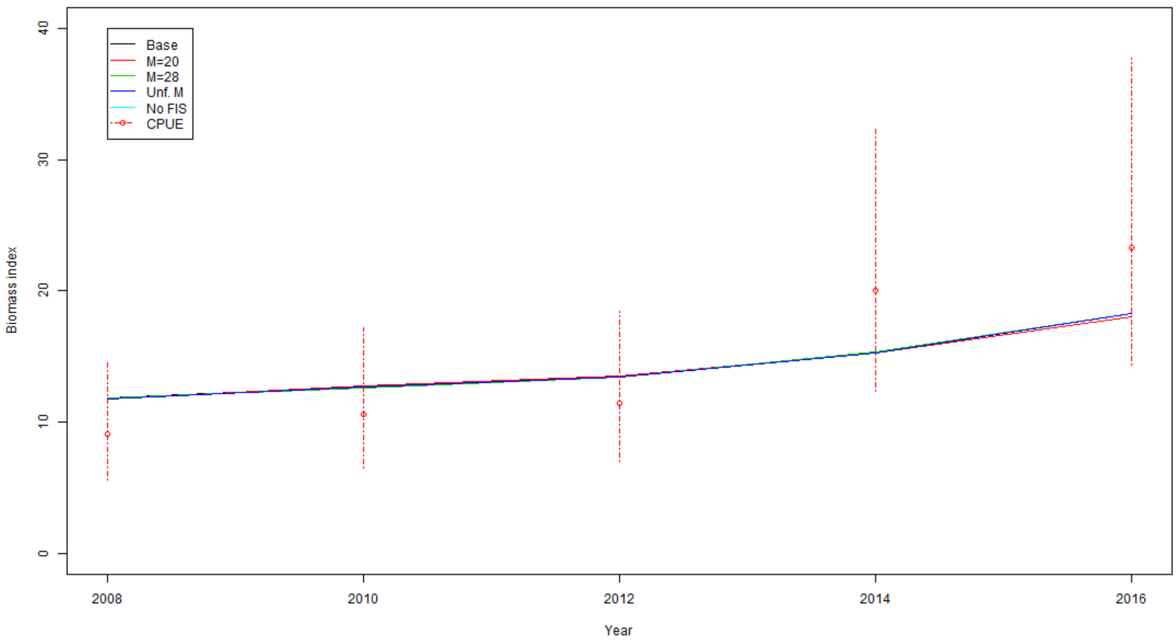

Figure 32: Western stock: MPD fit to the FIS indices for all of the final MPD runs.

The likelihood profile on M for the base model shows that the estimate is a trade-off between the higher values preferred by the non-trawl conditional age-at-length data and the lower values favoured by the trawl conditional age-at-length data (Figure 33). The estimate is robust to data weighting as there is no reason to treat the two data sets differently. In a reweighting, both would either be given less weight or more weight and the estimate of M would likely not change.

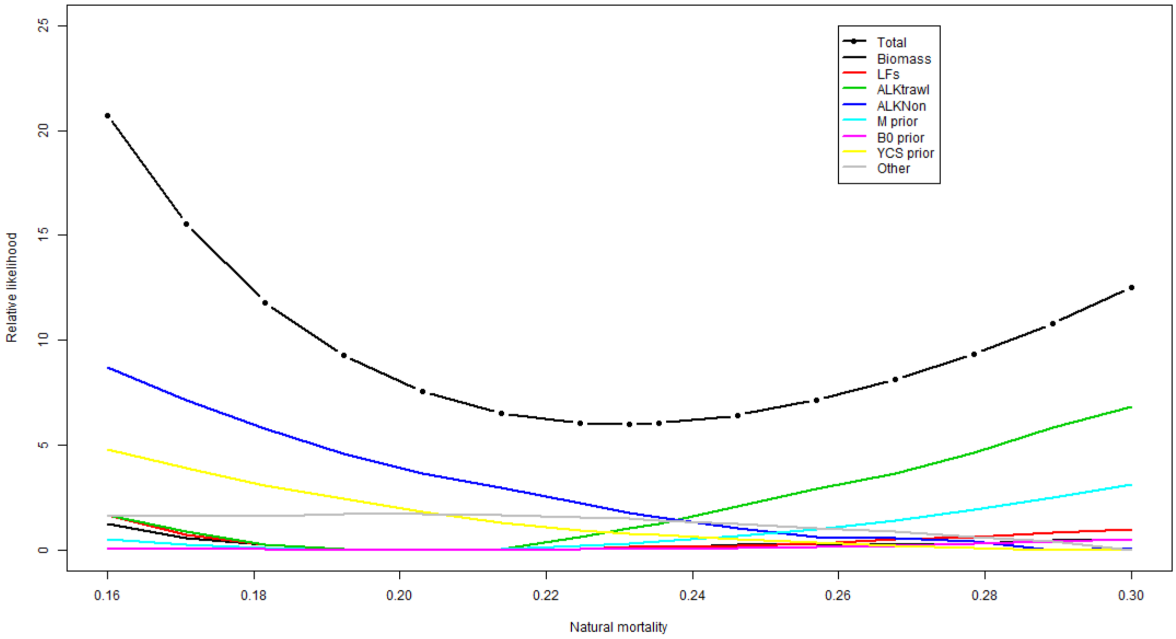

Figure 33: Western stock: Likelihood profile on M showing the contribution to the total likelihood for the different data sets, priors, and penalties for fixed values of M from 0.16 to 0.30. (Biomass = biomass indices, LFs = length frequencies, ALK = age-length data, non = non-trawl.)

The likelihood profile for B_0 shows that the length frequencies object to low values of B_0 while high values are opposed the trawl conditional age-at-length (Figure 34). Although a minor contributor to the overall likelihood the biomass indices also oppose low values of B_0 (Figure 34). Unlike the eastern stock, there is no strong trend in the estimates of M for given values of B_0 (Figure 35).

The growth estimates are very similar across model runs (Figure 36). The estimated selectivities for the FIS and the commercial fisheries show some patterns mainly associated with the fixed or estimated value of M (Figures 37-41). The estimated YCS also show a pattern associated with M (Figure 42).

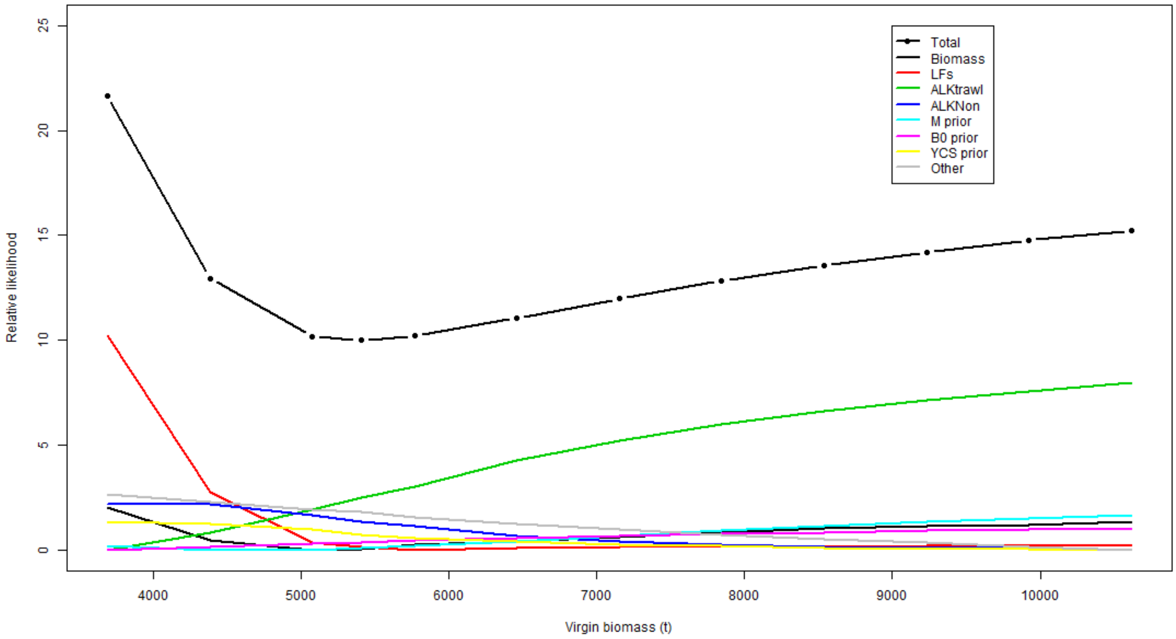

Figure 34: Western stock: Likelihood profile on B_0 showing the contribution to the total likelihood for the different data sets, priors, and penalties for fixed values of B_0. (Biomass = biomass indices, LFs = length frequencies, ALK = age-length data, non = non-trawl.)

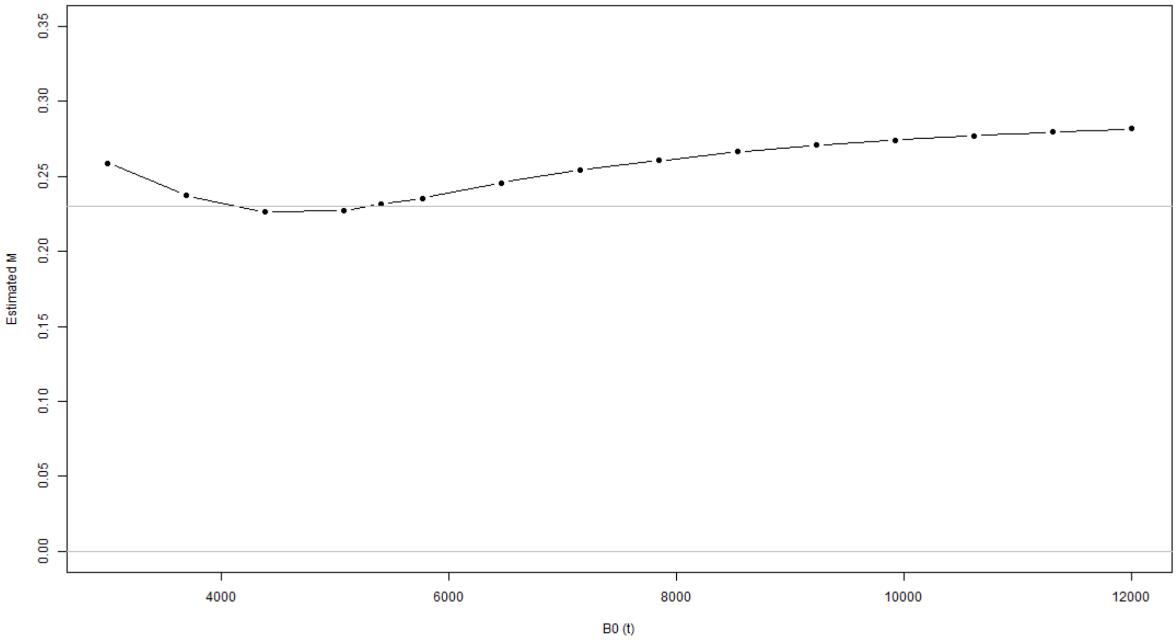

Figure 35: Western stock: MPD estimates of M for fixed values of B_0 (from the likelihood profile on B_0). The horizontal line is at M=0.23 the MPD estimate of M in the base model.

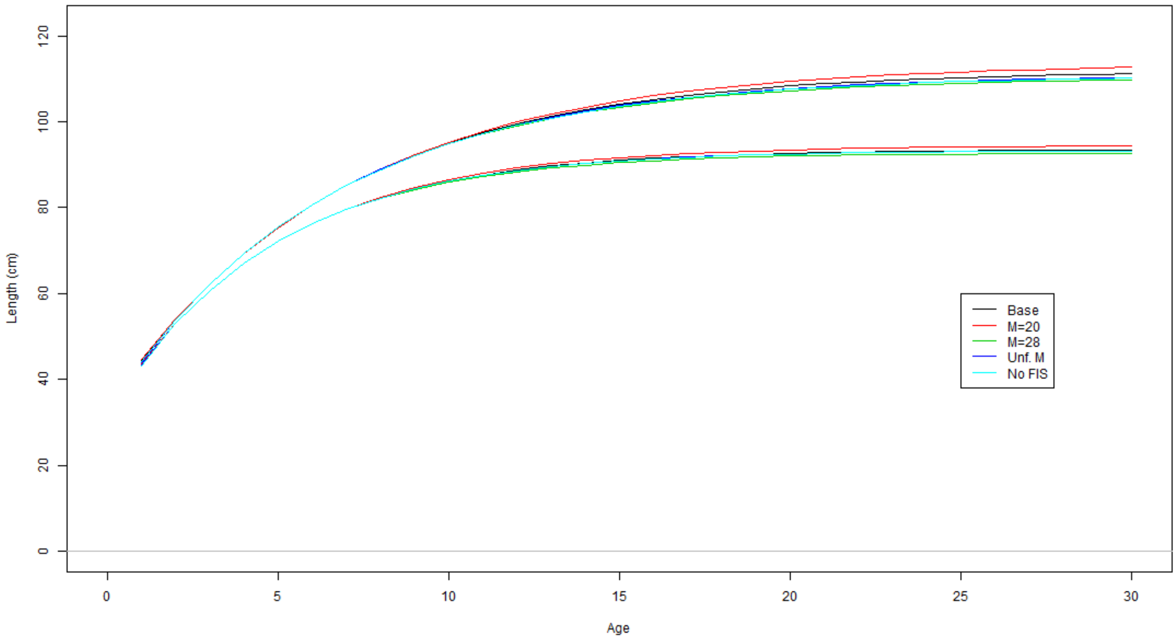

Figure 36: Western stock: MPD estimates of length at age for male (bottom group) and female (top group) ling for each of the final MPD runs.

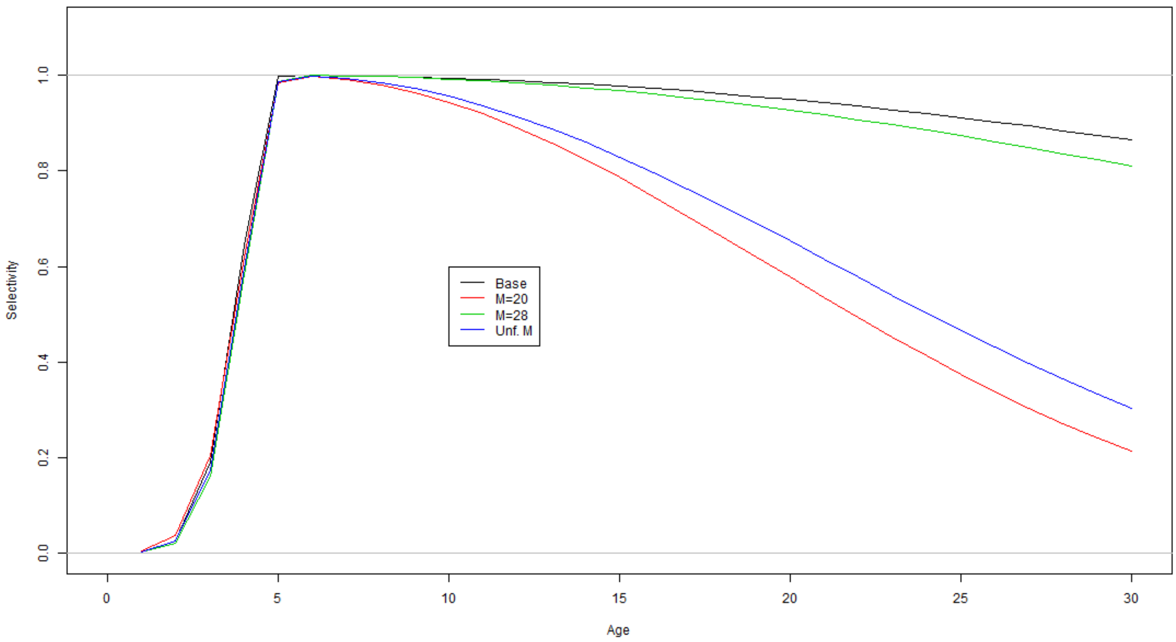

Figure 37: Western stock: MPD estimates of selectivity for the FIS for each of the final MPD runs that included the FIS data.

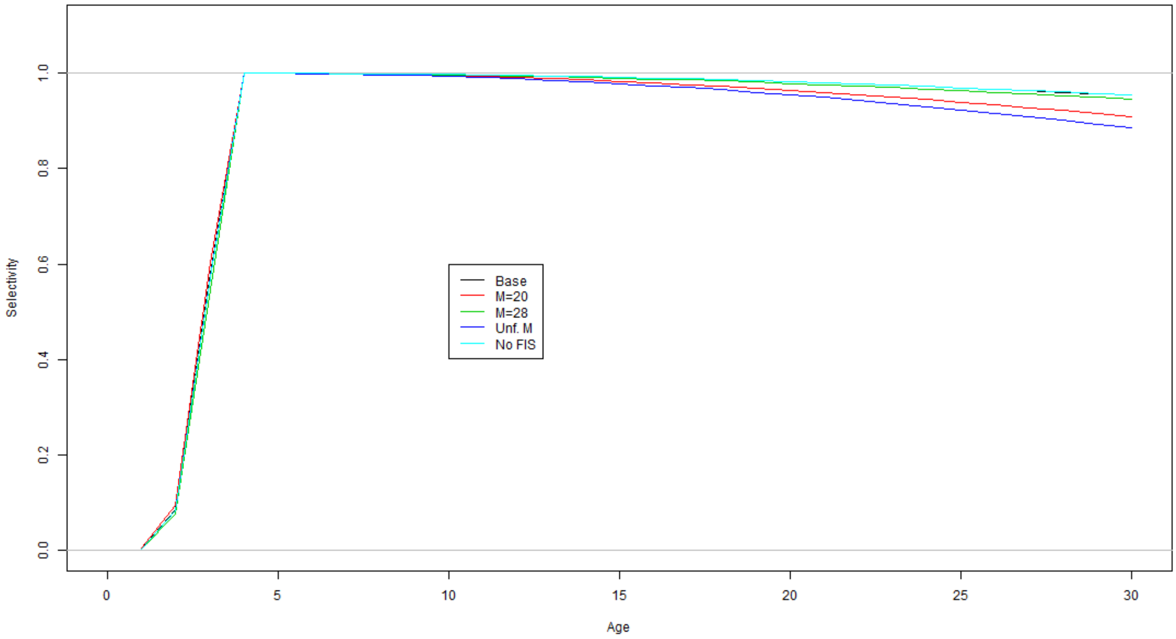

Figure 38: Western stock: MPD estimates of trawl selectivity in the first time block for each of the final MPD runs.

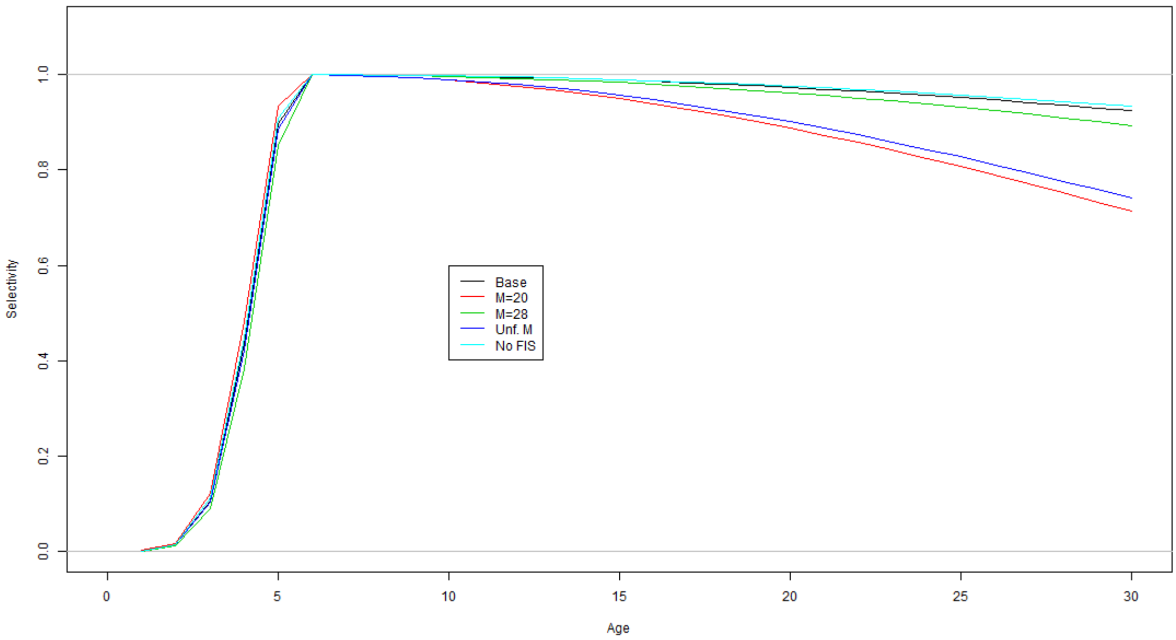

Figure 39: Western stock: MPD estimates of trawl selectivity in the second time block for each of the final MPD runs.

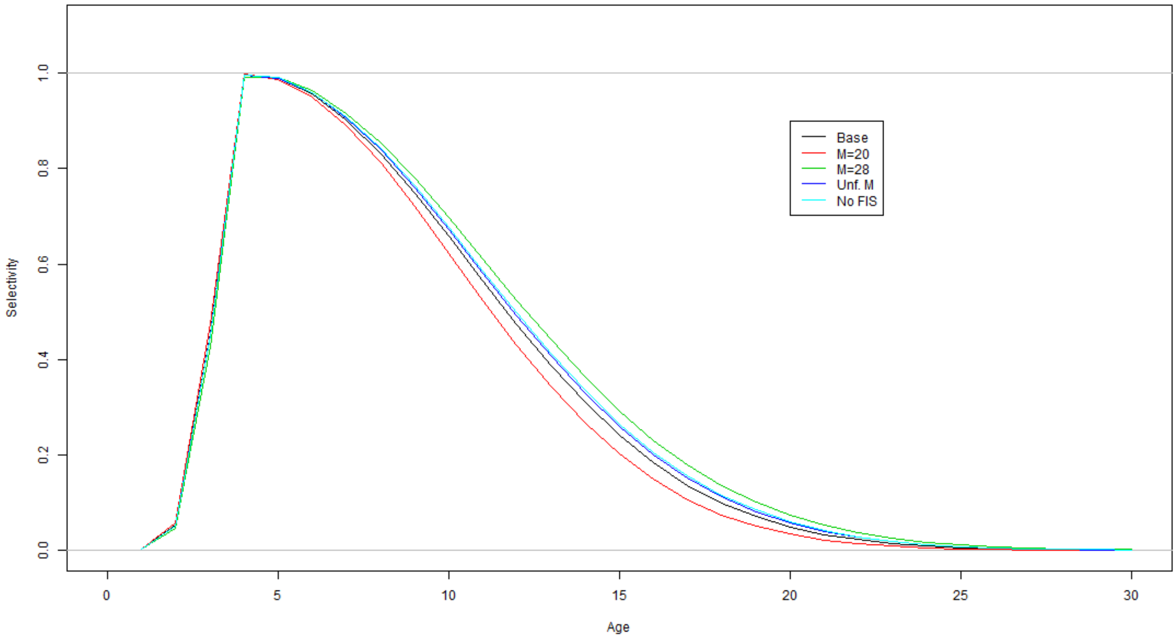

Figure 40: Western stock: MPD estimates of selectivity for port sampled ling caught by trawl for each of the final MPD runs.

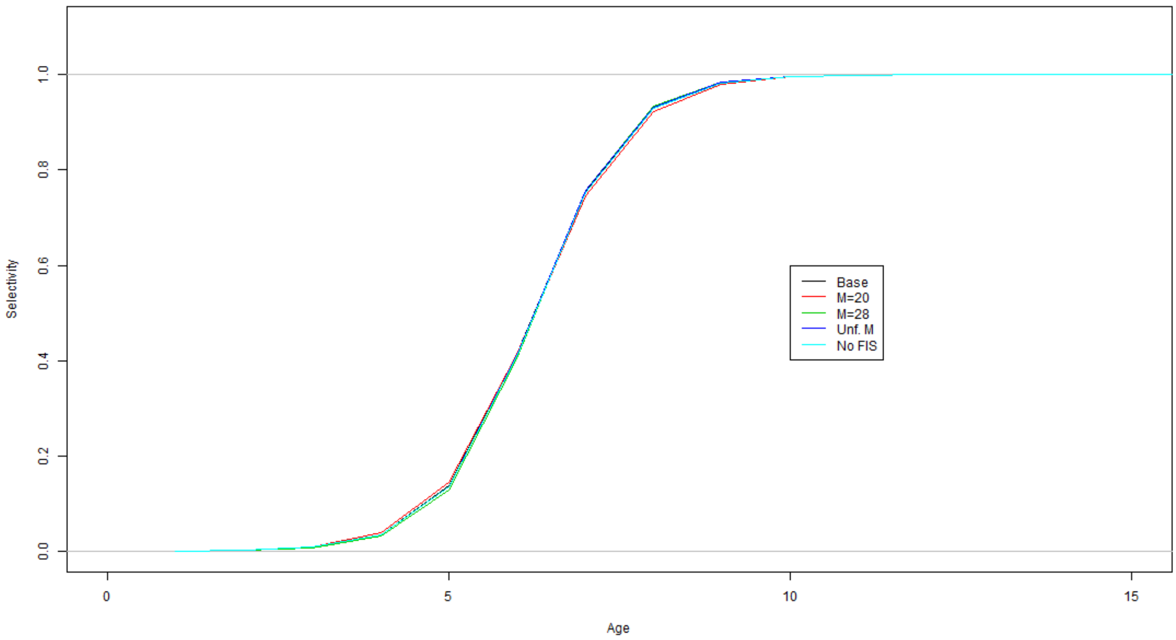

Figure 41: Western stock: MPD estimates of non-trawl selectivity for each of the final MPD runs.

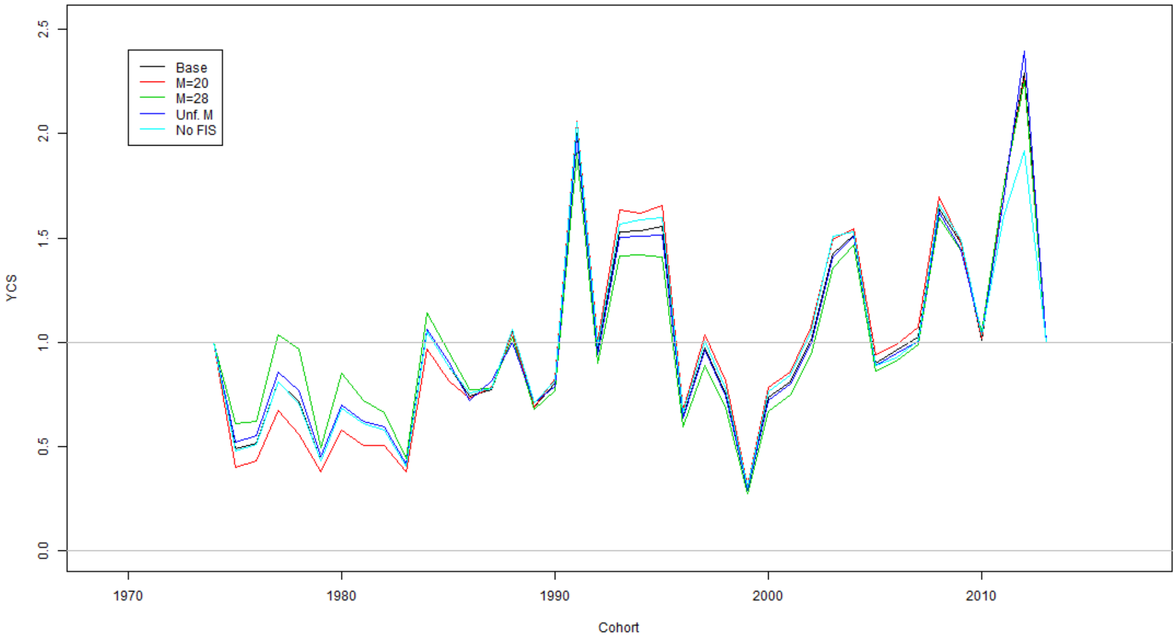

Figure 42: Western stock: MPD estimates of YCS for each of the final MPD runs.

The exploitation rates from the trawl and non-trawl fisheries are similar in a number of years with neither fishery having consistently higher exploitation rates (Figure 43). The average ratio of trawl exploitation rate to non-trawl exploitation rate for the period 2010-2013 is 1.1 (Figure 44). This ratio was used in constant catch projections to maintain the relative exploitation rates of the fisheries within the model. The period was chosen as it was just before the imposition of a series of changeable management actions in the east.

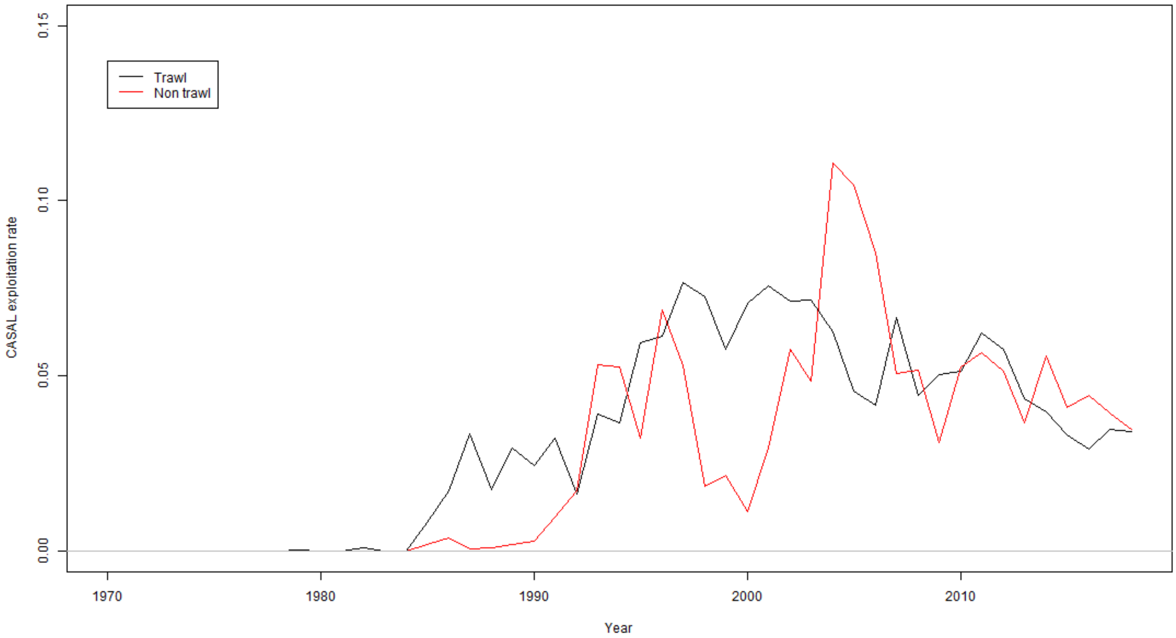

Figure 43: Western stock: MPD estimates of annual CASAL exploitation rates for the trawl and non-trawl fisheries in the base model.

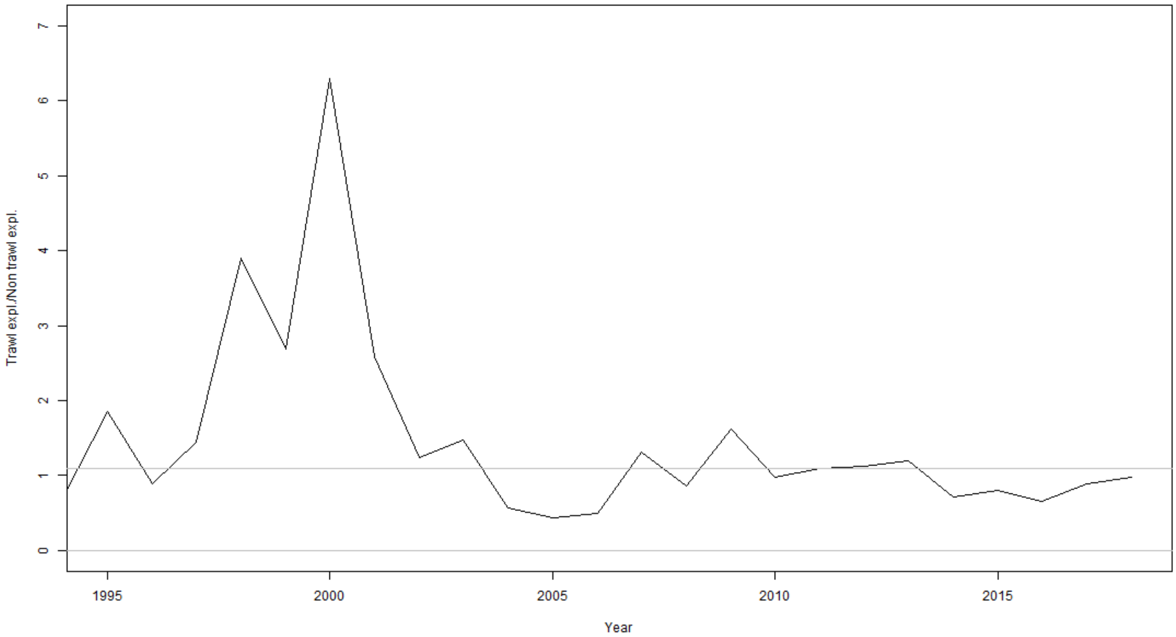

Figure 44: Western stock: MPD estimates of the trawl exploitation rate divided by the non-trawl exploitation rate in the base model. The average ratio for 2010-2013 inclusive is marked as a horizontal line at 1.1.

MCMC estimates

This section provides the MCMC estimates for several eastern models, including the eventual base model (reference model with M=0.23), and the base model results for the western stock. Point estimates and 95% CIs are provided for the free parameters and also RBC (for three years). Constant catch projections are also given.

Eastern stock

Three potential base models were offered to the second SERAG meeting because the initial choice of base model at the first SERAG meeting delivered a higher value of M than expected (Table 5). As stock status is highly dependent on M, with higher values of M giving higher stock status, the choice of base model was important (Table 5). After consideration of likelihood profiles on M for the western and eastern stock it was decided that the western estimate of M appeared robust but the eastern estimate was not. As there was no reason to believe that M would be different between the two stocks it was decided to fix M for the eastern stock at the western point estimate. The Period CPUE was believed to be implausible so the SERAG chose the M=0.23 run with the base CPUE as the base model.

The base model estimates current stock status at 30% B_0 with little or no chance that it is below the limit reference point (20% B_0) or above the target biomass (48% B_0) (Table 5, Figure 45).

Table 5: Eastern MCMC: estimates of *M*, virgin SSB, and current stock status for the three models offered as potential base models at the November SERAG (first three) and two additional sensitivities. The median and 95% CI are given. Also shown are the probabilities of current stock status being below 20% B_0, 30% B_0, or being at or above the target of 48% B_0. Results are given in bold for the base model (Base CPUE, M=0.23).

	M	**B_0 (t)**	**ss_{2018} (%B_0)**	**P(ss_{2018} < 0.2)**	**P(ss_{2018} < 0.3)**	**P(ss_{2018} ≥ 0.48)**
Base CPUE Estimate M	0.25 0.23–0.27	5350 4730–6070	35 25–47	0.00	0.19	0.02
Base CPUE M=0.23	**0.23**	**5900 5540–6450**	**30 22–42**	**0.01**	**0.51**	**0.00**
Period CPUE M=0.23	0.23	6110 5680–6730	36 28–48	0.00	0.06	0.02
Base CPUE M=0.20	0.20	7010 6620–7510	24 17–36	0.17	0.86	0.00
Linkall CPUE Estimate M	0.25 0.22–0.27	5270 4620–6060	28 19–41	0.05	0.66	0.00

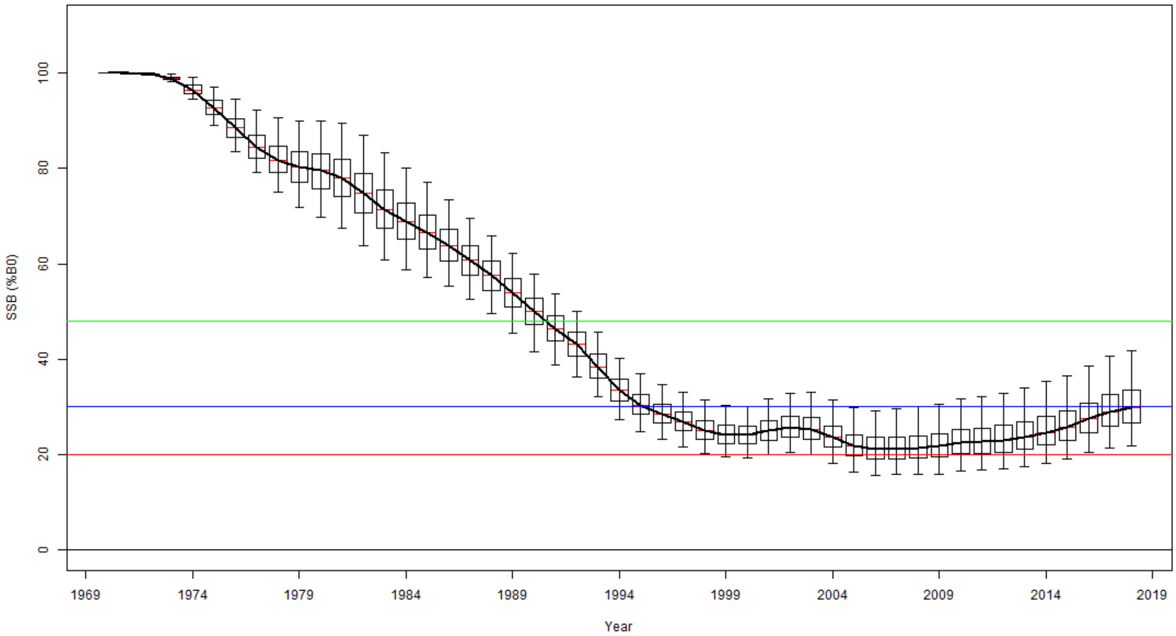

Figure 45: Eastern stock, base: MCMC estimates of stock status trajectory (SSB/B_0). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The medians are marked by red horizontal lines, within each box, which are joined by the solid black line. Horizontal lines are marked 20%, 30%, and 48% B_0.

There were no surprises in the estimated selectivities with the trawl and FIS selectivities being domed as expected (Figure 46) and the two non-trawl selectivities, which were forced to be flat-topped, being very similar (Figure 47).

The estimated YCS showed the same pattern as in previous assessments with strong cohorts in 1992 and 1996 and recent recruitment, showing some variation, but being about average (Figure 48).

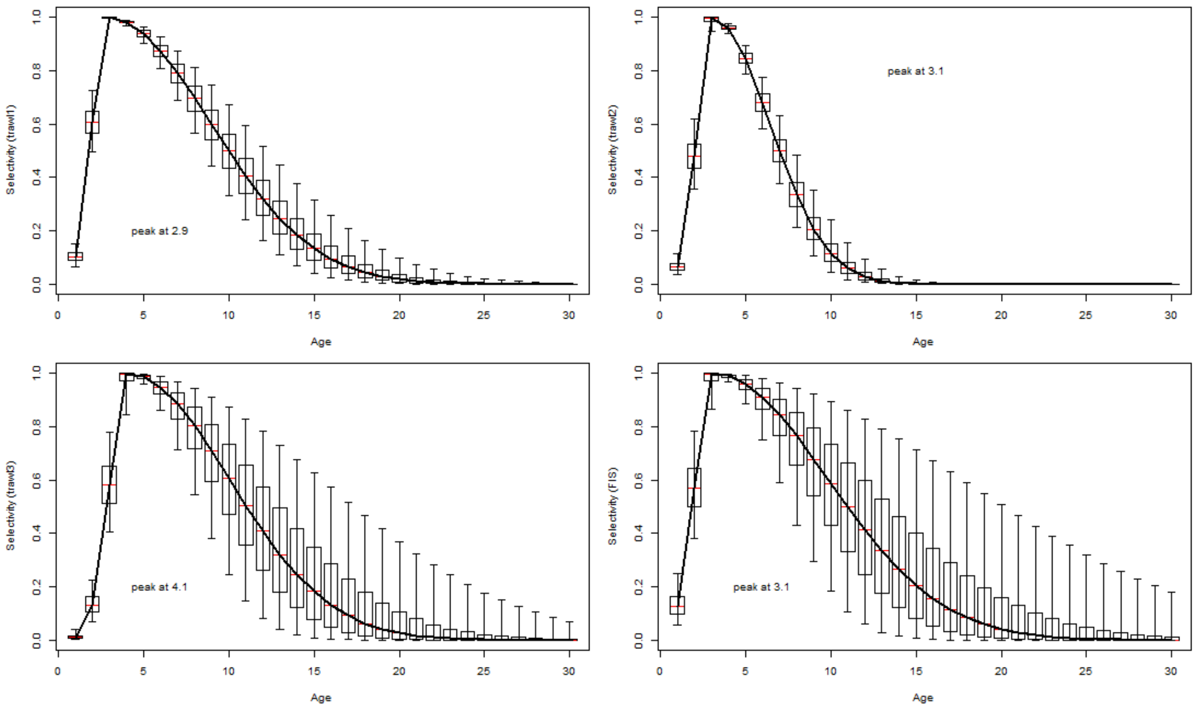

Figure 46: Eastern stock, base: MCMC estimates of selectivity for the trawl fishery in the three time blocks and also for the FIS. At each age the box covers the middle 50% of the distribution and the whiskers extend to 95%

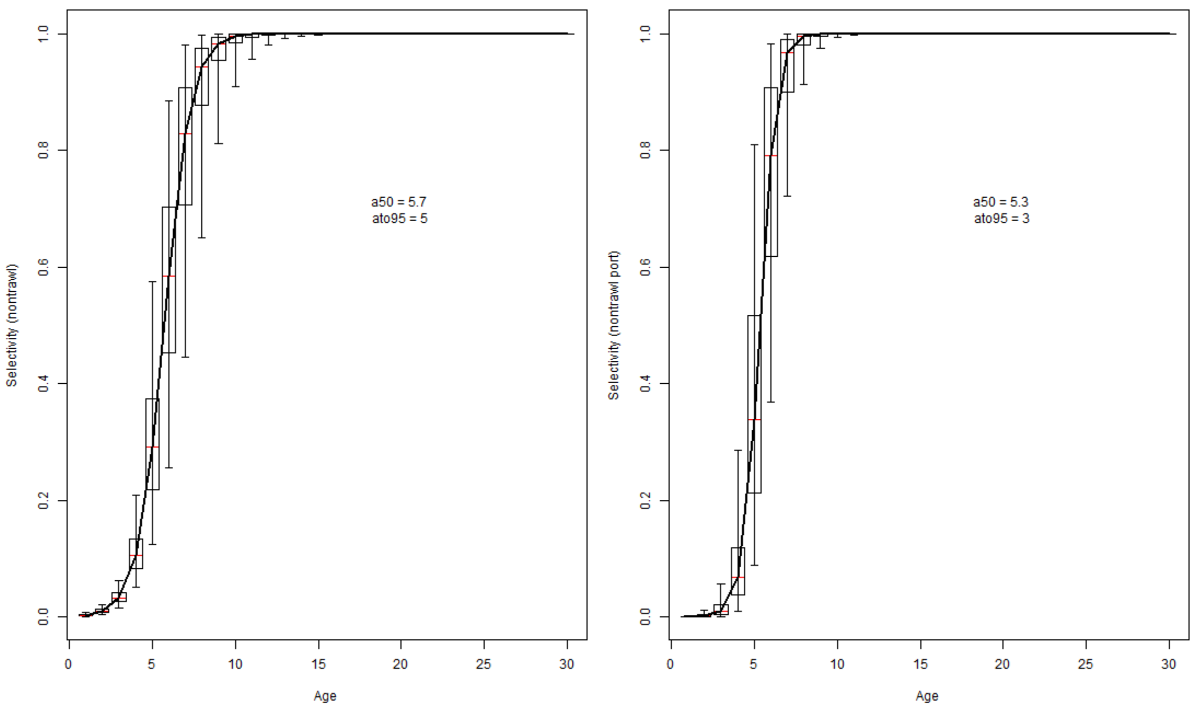

Figure 47: Eastern stock, base: MCMC estimates of selectivity for the non-trawl fishery for at-sea and port sampling. At each age the box covers the middle 50% of the distribution and the whiskers extend to 95%

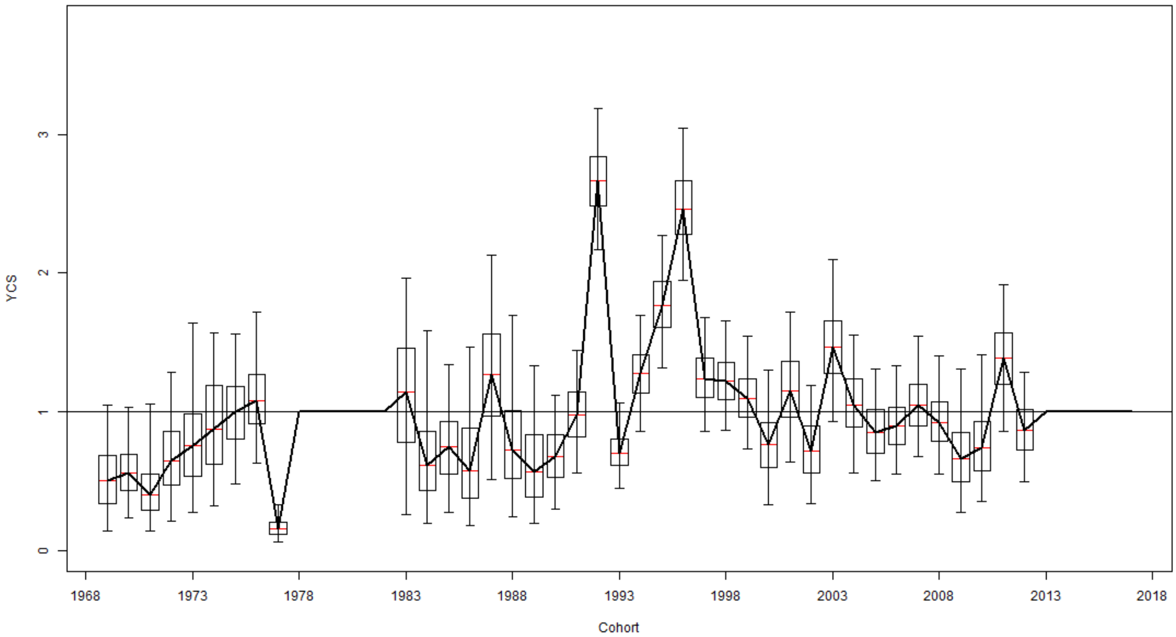

Figure 48: Eastern stock, base: MCMC estimates of YCS. Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The medians are marked by red horizontal lines, within each box, which are joined by the solid black line.

For the base model, the RBC was estimated for the next three years (assuming the RBC was caught in each previous year) (Table 6). The estimates are very imprecise because of the uncertainty in terms of current stock status (which determines the associated exploitation function through the harvest control rule) (Table 6). Long-term yield is precisely estimated because it is the yield when the stock is at equilibrium at 48% B_0 (Table 6). For the reference model the estimate of long-term yield is very similar to that from the base model but because of the higher estimated stock status the 2019 RBC is estimated to be much higher (although still imprecise) (Table 7).

Table 6: Eastern stock, base model (M=0.23): MCMC estimates of RBC and deterministic long-term yield for the generic harvest control rule.

	2019 RBC (t)	2020 RBC (t)	2021 RBC (t)	Long-term yield (t)
Median	260	330	430	570
95% CI	36–560	72–590	140–620	540–620

Table 7: Eastern reference, MCMC: estimates of 2019 RBC and deterministic long-term yield for the generic harvest control rule.

	2019 RBC (t)	Long-term yield (t)
Median	450	580
95% CI	120–620	550–630

MCMC constant catch projections

The projections at constant annual catch show that there is little risk of the eastern stock falling below the limit reference point for catches up to 550 t per year (Table 8). Expected spawning biomass increases from 2021 to 2028 for annual catches up to 600 t per year (Table 8).

The stock is expected to rebuild to the target of 48% B_0 with at least 50% probability in a reasonable timeframe (before 2050) for annual catches up to 500 t per year (Table 9). The estimated RBCs for the next three years, from the generic harvest control rule, are poorly estimated and low compared to annual catches that can safely be taken (compare Tables 6 and 8).

For all of the eastern MCMC models, including the two that estimate the lowest current stock status, the spawning biomass is expected to increase from 2021 to 2028 for constant catches of 500-550 t (Tables 10 and 11). The risk of falling below the limit reference point (20% B_0) also decrease over time for all of the models at catches of 500-550 t (Tables 10 and 11).

Table 8: Eastern stock: MCMC projection results for the base model showing the expected SSB in 2021 and 2028 under different constant catch scenarios with the associated probabilities of being below 20% or 30% B_0 and at or above the target of 48% B_0.

Catch (t)	E(B_{21}) (%B_0)	E(B_{28}) (%B_0)	P(ss_{21} < 0.2)	P(ss_{28} < 0.2)	P(ss_{21} < 0.3)	P(ss_{28} < 0.3)	P(ss_{21} ≥ 0.48)	P(ss_{28} ≥ 0.48)
0	42	72	0.00	0.00	0.05	0.00	0.23	0.99
300	37	53	0.01	0.00	0.20	0.01	0.10	0.66
400	35	47	0.02	0.01	0.29	0.06	0.07	0.45
450	34	44	0.02	0.01	0.34	0.10	0.06	0.34
500	33	41	0.04	0.02	0.38	0.17	0.05	0.25
550	32	38	0.05	0.05	0.42	0.27	0.04	0.18
600	32	35	0.06	0.11	0.46	0.37	0.04	0.14
650	31	31	0.08	0.18	0.51	0.50	0.03	0.08

Table 9: Eastern stock: rebuild years for the base model under different constant catch scenarios.

Annual catch (t)	Rebuild year	Years to wait
0	2023	5
300	2026	8
400	2030	12
450	2033	15
500	2040	22
550	>2050	>32

Table 10: Eastern stock: MCMC projection results for all eastern models showing the expected SSB in 2021 and 2028 under a constant annual catch of 500 t with the associated probabilities of being below 20% or 30% B_0.

Model	**E(B_{21}) (%B_0)**	**E(B_{28}) (%B_0)**	**P(ss_{21} < 0.2)**	**P(ss_{28} < 0.2)**	**P(ss_{21} < 0.3)**	**P(ss_{28} < 0.3)**
Per. CPUE						
M=0.23	40	47	0.00	0.00	0.10	0.07
Est. M	38	45	0.01	0.01	0.19	0.10
M=0.23 (Base)	**33**	**41**	**0.04**	**0.02**	**0.38**	**0.17**
Linkall	32	40	0.08	0.04	0.46	0.23
M=0.20	27	34	0.16	0.10	0.69	0.38

Table 11: Eastern stock: MCMC projection results for all eastern models showing the expected SSB in 2021 and 2028 under a constant annual catch of 550 t with the associated probabilities of being below 20% or 30% B_0.

Model	**E(B_{21}) (%B_0)**	**E(B_{28}) (%B_0)**	**P(ss_{21} < 0.2)**	**P(ss_{28} < 0.2)**	**P(ss_{21} < 0.3)**	**P(ss_{28} < 0.3)**
Per. CPUE						
M=0.23	39	44	0.00	0.01	0.12	0.10
Est. M	37	42	0.02	0.03	0.23	0.15
M=0.23 (Base)	**32**	**38**	**0.05**	**0.05**	**0.42**	**0.27**
Linkall	31	37	0.10	0.09	0.51	0.32
M=0.20	26	31	0.21	0.17	0.71	0.49

Western stock

Current stock status was estimated to be well in excess of the target of 48% B_0 with no risk of the stock being below the limit reference point or even the target reference point (Table 12, Figure 49).

Table 12: Western, base: MCMC estimates of *M*, virgin SSB, and current stock status. The median and 95% CI are given. Also shown are the probabilities of current stock status being below 20% B_0, 30% B_0, or being at or above the target of 48% B_0.

	M	**B_0 (t)**	**ss_{2018}(%B_0)**	**P(ss_{2018} < 0.2)**	**P(ss_{2018} < 0.3)**	**P(ss_{2018} ≥ 0.48)**
Base	0.23	5360	84			
	0.20–0.26	4720–6220	69–100	0.00	0.00	1.00

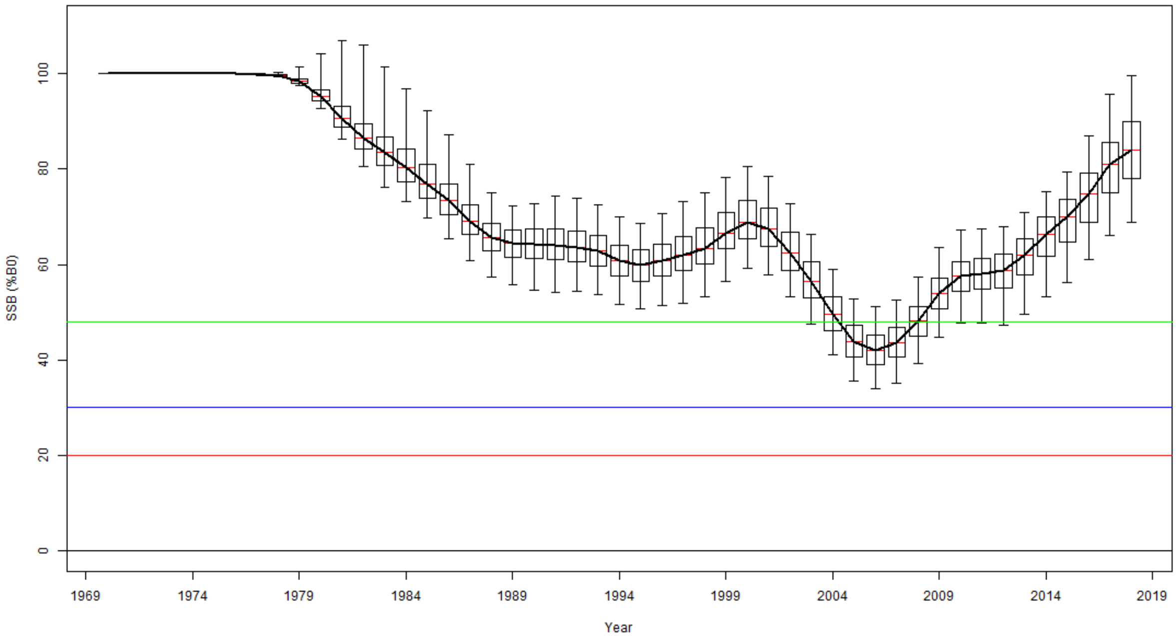

Figure 49: Western stock: MCMC estimates of stock status trajectory (SSB/B_0) for the base model. Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The medians are marked by red horizontal lines, within each box, which are joined by the solid black line. Horizontal lines are marked 20%, 30%, and 48% B_0.

There were no surprises in the estimated selectivities with the trawl selectivities being partly domed as expected and the port-based sampling being highly domed (Figure 50). This was the same pattern seen in previous assessments. The FIS selectivity was similar to the two trawl selectivities (Figure 51).

The estimated YCS showed the same pattern as in previous assessments except that the two newly estimated YCS appear to be very strong, albeit poorly estimated at this stage (Figure 52).

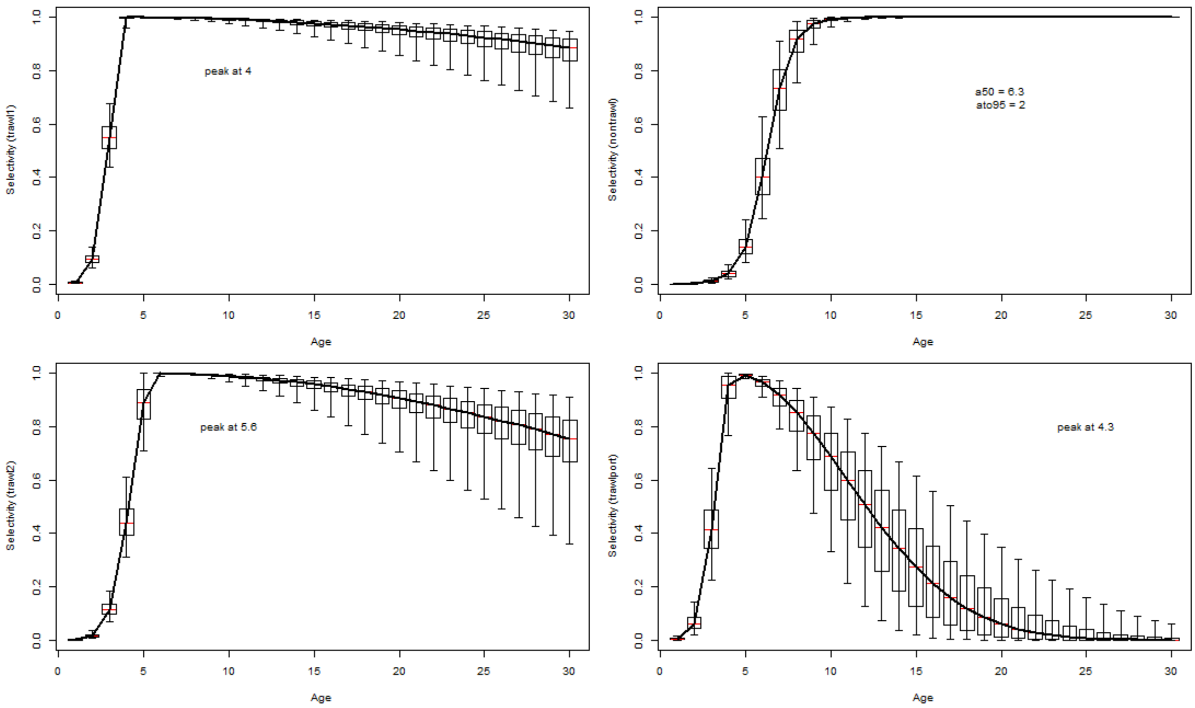

Figure 50: Western stock: MCMC estimates of selectivity for the trawl and non-trawl fisheries in the base model. At each age the box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The medians are marked by red horizontal lines, within each box, which are joined by the solid black line.

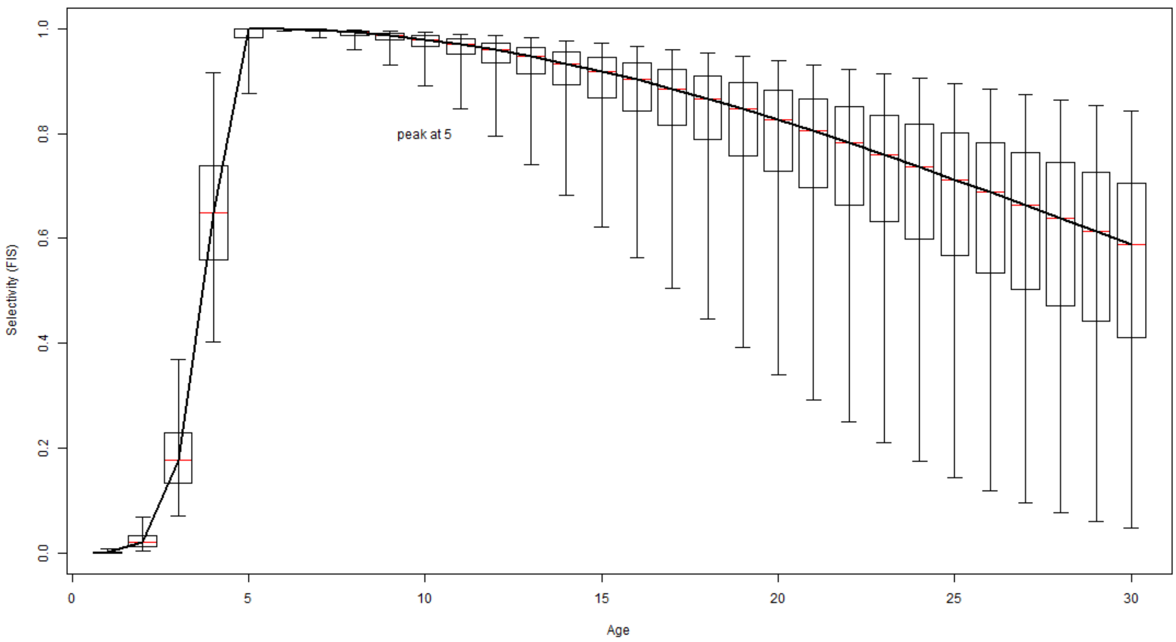

Figure 51: Western stock: MCMC estimates of selectivity for the FIS in the base model. At each age the box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The medians are marked by red horizontal lines, within each box, which are joined by the solid black line.

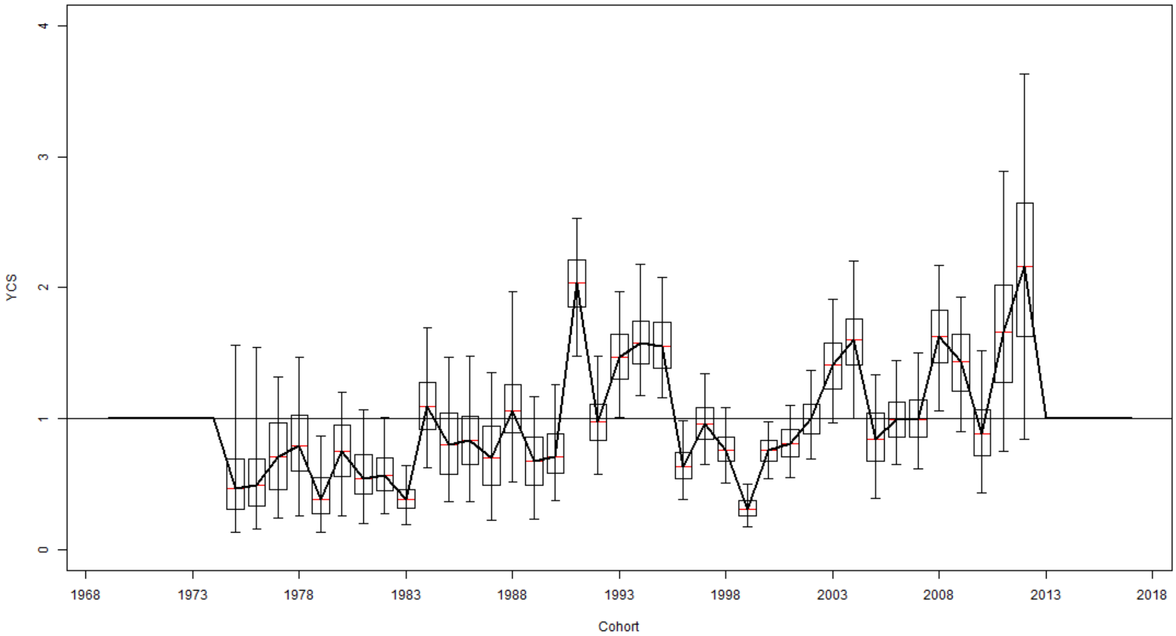

Figure 52: Western stock: MCMC estimates of YCS for the base model. Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The medians are marked by red horizontal lines, within each box, which are joined by the solid black line

The estimated RBC over the next three years, from the generic harvest control rule, is well in excess of the estimated long-term yield because the stock is estimated to be well above the target biomass (Table 13).

Table 13: Western stock, base model: MCMC estimates of RBC and deterministic long-term yield for the generic harvest control rule.

	2019 RBC (t)	**2020 RBC (t)**	**2021 RBC (t)**	**Long-term yield (t)**
Median	1150	1060	970	690
95% CI	770–1660	700–1550	630–1440	550–860

MCMC constant catch projections

Constant catch projections show that there is little risk of the stock falling below the limit reference point in the next 10 years for catches up to 1000 t per year (Table 14).

Table 14: Western, base: MCMC projection results showing the expected SSB in 2021 and 2028 under different constant catch scenarios with the associated probabilities of being below 20% or 30% B_0 and at or above the target of 48% B_0.

Catch (t)	$E(B_{21}/B_0)$	$E(B_{28}/B_0)$	$P(ss_{21} < 0.2)$	$P(ss_{28} < 0.2)$	$P(ss_{21} < 0.3)$	$P(ss_{28} < 0.3)$	$P(ss_{21} \geq 0.48)$	$P(ss_{28} \geq 0.48)$
600	78	65	0.00	0.00	0.00	0.00	1.00	0.88
700	76	60	0.00	0.00	0.00	0.02	1.00	0.78
800	74	54	0.00	0.00	0.00	0.04	0.99	0.64
900	72	48	0.00	0.02	0.00	0.12	0.98	0.51
1000	70	43	0.00	0.05	0.00	0.19	0.97	0.35

Conclusion and discussion

As in previous years, the western pink ling assessment presented few technical difficulties and the estimated stock status was well above the target of 48% B_0. No sensitivities were taken through to MCMC because it matters little how the data are treated or weighted or whether M is estimated or fixed low or high, the estimated stock status will always be well above the target. This is because the trawl CPUE time series continues to increase. Annual long-term yield is estimated at 550–860 t (95% CI). Stochastic projections show little or no risk to the stock in the next few years for total removals of up to 1000 t per year.

The eastern assessment was, as usual, somewhat problematic. The changeable management regimes to limit eastern catch make the trawl CPUE analysis problematic. The approach taken in the 2015 assessment of estimating "period effects" for each management regime was not successful this year as the resulting CPUE time series showed an unrealistic increase from 2015 through to 2017. An alternative method of adjusting for discards in the CPUE analysis was used but this probably understates the recent increase in biomass because it took no account of avoidance behaviour by vessels (which may have occurred in such a way that it was not picked up by the standardisation).

The estimation of M was also a problem for the eastern assessment. The approach used in 2013 and 2015 was again used where the posterior of M in the western assessment was used as the prior for M in the eastern assessment. However, the subsequent estimate of 0.25 is starting to get a little high for ling and there is no reason to believe that M in the east should be higher than M in the west. The likelihood for eastern M suggested gave little comfort and suggested that the estimate of M in the east was far from robust. Therefore, the base model for the eastern assessment used M fixed at 0.23 (the point estimate in the western assessment).

With the use of the somewhat conservative CPUE time series and a somewhat conservative value of M the eastern base assessment is precautionary in nature. However, the stock is estimated to have increased in recent years and at catches up to 550 t per year is still expected to increase. The stock is expected to rebuild to the target of 48% B_0 with at least 50% probability in a reasonable timeframe (before 2050) for annual catches up to 500 t per year.

For all of the eastern models, including the two that estimate the lowest current stock status, the spawning biomass is expected to increase from 2021 to 2028 for constant annual catches of 500-550 t. The risk of falling below the limit reference point (20% B_0) decreases over time for all of the models at annual catches of 500-550 t. Annual long-term yield is estimated at 540-620 t (95% CI).

Acknowledgements

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Appendix A: discards, catch history, and trawl CPUE

This appendix describes the updating of the catch histories including discards during the recent period of trip limits on the eastern stock. The updating of the trawl CPUE is also described.

Methods

The updating of catch histories and CPUE indices is normally straightforward. However, as in the 2015 update, the recent and changeable trip limits on the eastern ling fishery make this update relatively complicated. The stock assessment models require data on catch (landings plus discards) rather than just landings. The trip limits since 2013 would be expected to cause changeable levels of discarding in the eastern fisheries. The scale of the discards needs to be quantified and used to prepare the eastern catch history and to give context to the eastern CPUE indices.

AFMA supplied a list of the different eastern trip limits:

26 September 2013 to 30 April 2014:	50 kg per day
1 May 2014 to 13 February 2015:	250 kg per day
14 February 2015 to 19 May 2015:	50 kg per day
20 May 2015 to 30 April 2016:	175 kg per day

From 1 May 2016 SETFIA arrangements.

CSIRO supplied ISL with the raw discard data from the ISMP that are used to calculate annual fishery wide discard rates (e.g., Upston and Klaer 2013). These data were used to estimate discards by calendar year and for the above time periods (to the end of 2017) for the eastern and western trawl and non-trawl fisheries. The stock and fishery specific discards were used to move from estimated landings to catch estimates for 2013-2017.

Stock and method definition

The eastern stock is associated with zones 10, 20, and 30 (with catches and data from zone 60 assigned to zone 20). The western stock is associated with zones 40, 50, and 80 (although zone 80 is only included in terms of landings).

For each stock, the model has a trawl fishery and a non-trawl fishery. The trawl fishery is demersal trawl, while non-trawl is every other method (mainly longline).

Discard estimates

Two different approaches were used to estimate the scale of discards by calendar year and in the periods affected by the trip limits or the voluntary SETFIA arrangements which limited catches in the east (restricted to the end of 2017):

1 January 2013 to 25 September 2013	no limit
26 September 2013 to 30 April 2014:	50 kg per day
1 May 2014 to 13 February 2015:	250 kg per day
14 February 2015 to 19 May 2015:	50 kg per day
20 May 2015 to 30 April 2016:	175 kg per day
1 May 2016 to 31 December 2017:	SETFIA arrangements

The ISMP data consist of station records with the associated weight of retained and discarded ling. The data are collected by observers who are on a vessel for a whole trip. The observers sample most shots while they are onboard.

For the ith *trip* let:

d_i = total observed discarded weight of ling
l_i = total observed landed whole weight of ling.

In terms of modifying landings, we wish to estimate the multiplier that should be applied to the landings to give the catch. That is, we want to estimate m: $C = m\,L$ where L is a given landing and C is the associated catch.

For each fishing method and each year or period under consideration two estimates were made of m:

$$\widehat{m} = \frac{\sum_i l_i + d_i}{\sum_i l_i}$$

and

$$\widetilde{m} = \frac{1}{n}\sum_i \frac{l_i + d_i}{l_i}$$

where summation is over the trips within the period given the fishing method. For both estimation methods, trips which landed less than 50 kg of ling were excluded. This avoids potentially very large estimates of m from trips which may have landed almost no ling and discarded twice as much. The first method is robust to those sorts of trips (unless they were the only type of trips sampled during a particular year) and is “self-weighting” in terms of ling landings (with trips that landed lots of ling getting more weight). In 2015 I preferred the second method because intuitively it is a more direct simple-random-sampling estimate of m (i.e., assuming the allocation of observers to trips is random). In 2015, the results were very similar for both methods. However, this time results differ by method and on reflection method 1 should be preferred as it is a consistent estimator (that is, with increasing sample size it gets closer and closer to the true value).

Catch estimates

CSIRO supplied a spreadsheet of landing and discard estimates for pink ling from 1994 to 2017. The table included Commonwealth landing and discard estimates and State catches. These were totals combined across stocks and methods. CSIRO also supplied GenLog data for ling consisting of station records and estimated whole weight of landed ling. The catch histories used in the 2013 assessment were constructed by Andre Punt using similar data where the total catches were split between stocks and fishing methods using the proportions from the GenLog data.

The total catches from the CSIRO table were compared with the total catches from the 2015 assessment over the period 1994-2014 and found be almost identical up to 2012. Therefore, the model catch histories from the 2015 assessment were updated only for 2013, 2014, and 2015. The catch history was extended to the end of 2018.

For 2013 to 2017 inclusive the periods of trip limits in the east had to be accounted for using period, stock, and fishing-method specific discard estimates. The Commonwealth landings for each calendar year were split by stock and fishing method using the GenLog proportions. For the west, year and fishing-method specific discards were then added to give the final catches. In the east, the Commonwealth catches were split by period within method to allow the different discard multipliers to be applied (one for each period). The Commonwealth catches by calendar year were then totaled and the NSW catches added to the east in proportion to the Commonwealth catches. The other state catches were within rounding error and ignored.

The assumed catches for 2018 were calculated by scaling down the 2018 TAC by the ratio of the 2017 total catch to the 2017 TAC and then using the 2017 proportions across stock and method to split the total catch.

CPUE trawl analysis

The methods used by ISL in the 2013 and 2015 assessments were applied (Cordue 2013, 2015). However, in some eastern runs, "period effects" were estimated to account for the discard and avoidance behaviour since 2013 due to the different trip limits.

The eastern and western trawl fisheries were modelled separately. When the eastern "period effects" were not estimated, the form of the models was the same for both east and west:

$$\log(\text{retained whole ling}) \sim \text{year} + \text{month} + \text{DorN} + \text{hours} + \text{depth} + \text{latitude} + \text{vessel}$$

All explanatory variables were categorical:

year:	1986-2017
month:	1-12
DorN:	four codes: day (D), night (N), mixed (M), and unknown (U)
hours:	cut into a factor with 12 levels from 0.5-10 hrs (west) and 10 levels from 0.5-8 hrs (east)
depth:	cut into a factor with 11 levels from 200-750 m (50 m bins)
latitude:	cut into a factor with 9 levels (east) and 8 levels (west)
vessel:	individual effects for any vessel present in at least three years within a "block"

For the east, the potential changes in vessel effects were modelled by allowing most vessels to change their vessel effect between blocks of time:

east: 1986-1999, 2000-2006, 2007-2017.

The split from 2006-2007 is indicated by the timing of the structural adjustment and also by the logbook data where the number of vessels approximately halves from 2006 to 2007. The eastern split from 1999-2000 is indicated by advice from the industry that ling quota associated with eastern trawl vessels was sold to support the developing line fishery (and also supported by logbook data – see Cordue 2013). In the 2013 assessment time-blocking of vessel effects made no difference to the western indices and so it was not done for this assessment.

The link between blocks was maintained by requiring that some vessels retained a constant vessel effect over the break points. This is needed to ensure that vessel and year effects are not confounded within a block. The same linking vessels from the 2013 and 2015 assessments were used in this analysis. For each pair of blocks, candidate linking vessels had been determined and ordered from "best" to "worst" in terms of consistency of fishing behaviour (Cordue 2013). As in 2013 and 2015, the base CPUE model uses the top three linking vessels for each pair of blocks.

In the eastern model, to account for the additional discards and avoidance behaviour (which is not compensated for by other effects) since 2013 a "period effect" was estimated. This was a categorical variable with six levels:

Period 1:	1 January 1986 to 25 September 2013	no limit
Period 2:	26 September 2013 to 30 April 2014	50 kg per day
Period 3:	1 May 2014 to 13 February 2015	250 kg per day
Period 4:	14 February 2015 to 19 May 2015:	50 kg per day
Period 5:	20 May 2015 to 30 April 2016:	175 kg per day
Period 6:	1 May 2016 to 31 December 2017:	SETFIA arrangements

The period effects are not strictly speaking confounded with the year effects (which are calendar years). However, there is a very close relationship as the combined product of year effects and period effects is better determined than the individual year and period effects. For example, if the Period 6 effect was halved and the 2017 year effect was doubled it would only affect the residuals for 1 May 2016 to 31 December 2016.

To investigate the robustness of the estimated period effects, alternative models were tried including only estimating three period effects (Period 1 as above, a second period including all of the trip limits, and a final period for the SETFIA arrangements).

Results

Discard estimates

In the east, there were 26 trawl trips with observed discards in 2013 and 2014 (with at least 50 kg of ling retained) and there were 9 such non-trawl trips (Table A1). In Period 2 there were no non-trawl trips but there were few landings so the lack of a data-based discard estimate is not a concern.

Table A1: The number of ISMP "trips" (defined as a gap of at least 3 days between observed operations) in the east during the five different periods of trip limits and the SETFIA arrangements since 1 May 2016.

	Trawl	Non-trawl
1 Jan. 2013 to 25 Sep. 2013	8	6
26 Sep. 2013 to 30 Apr. 2014	8	0
1 May 2014 to 13 February 2015	12	3
14 February 2015 to 19 May 2015	4	1
20 May 2015 to 30 April 2016	16	1
1 May 2016 to 31 December 2017	27	1

The eastern estimates of m were generally similar for the two methods (Table A2). However, there were enough differences that it does matter which method is used to adjust the landings to catches. Method 1 is to be preferred as it is a consistent estimator. For eastern trawl, the landings multipliers range from 1.18 to 1.49 (method 1) during the period of trip limits. There is a substantial drop from 1.49 to 1.06 when the SETFIA arrangements began (Table A2). The estimated adjustments for non-trawl are minor (Table A2).

Table A2: Estimates of the landings multiplier (*m*) in the east during the five different periods of trip limits and the SETFIA arrangements since 1 May 2016. Two different estimation methods were used (M1 = method 1 = ratio of sums; M2 = method 2 = mean of ratios). * For the non-trawl, in the second period, an educated guess was made for *m* as there were no data.

	Trawl M1	Trawl M2	Non-trawl M1	Non-trawl M2
1 Jan 2013 to 25 Sep 2013	1.00	1.01	1.00	1.00
26 Sep 2013 to 30 Apr 2014	1.43	1.45	1.05*	No data
1 May 2014 to 13 Feb 2015	1.18	1.15	1.02	1.04
14 Feb 2015 to 19 May 2015	1.19	1.95	1.00	1.00
20 May 2015 to 30 Apr 2016	1.49	1.37	1.00	1.00
1 May 2016 to 31 Dec 2017	1.06	1.03	1.01	1.01

In the west only minor discarding appeared to occur since 2013 (Table A3).

Table A3: Point estimates of the landings multiplier (*m*) for trawl and non-trawl in the west since 2013 (using method 1). * Educated guess as there were no data.

	Trawl	Non-trawl
2013	1.02	1.02
2014	1.00	1.02
2015	1.02	1.00
2016	1.03	1.00*
2017	1.03	1.00

Catch estimates

The eastern and western stock assessment models each have a trawl and a non-trawl fishery. The model catch histories used in the 2015 assessment were updated with revisions to 2013, 2014, and 2015 and the addition of catches in 2016, 2017 and 2018 (assumed).

The new estimates in 2013 to 2015 are higher overall than the values used in the 2015 assessment (Table A4).

Table A4: Model catch histories by stock and fishing method for 2013 to 2018. The catches (t) are landings plus estimated discards. For 2013 to 2015 the values used in the 2015 assessment are given in parentheses.

	East		West		Total
	Trawl	Non-trawl	Trawl	Non-trawl	East+West
2013	(247) 267	(117) 125	(300) 329	(153) 162	(817) 883
2014	(311) 383	(58) 67	(283) 320	(234) 265	(886) 1035
2015	(306) 384	(57) 90	(279) 280	(230) 210	(872) 964
2016	343	107	274	245	969
2017	422	139	352	235	1148
2018	408	135	341	227	1111

CPUE analysis

Eastern trawl

The standardized CPUE indices estimated from the 2018 dataset applying the same methods as in 2015 shows a very strong increase from 2015 through to 2017 (Figure A1). From 1986 to 2014 the indices are very similar to those estimated in the 2015 assessment (when period effects were first estimated).

The estimated period effects for the first 5 periods are slightly lower than the reciprocal of the corresponding landings multipliers (Figure A2). This is consistent with the period effect being a combination of discards and an avoidance behaviour (i.e., a reduction in ling catch rate due to a vessel shifting the depth and/or position of tows within a given depth class and latitude class). The period effect for Period 6 is much lower than expected given the minimal landings multiplier of just 1.06 for the period (Figure A2). Taken at face value it implies a very strong avoidance behaviour by the fishers in Period 6 when the SETFIA arrangements were in place. However, the corresponding year effects in 2016 and 2017 appear unrealistic.

When a smaller number of period effects were estimated (3 periods: no trip limit, some trip limit, SETFIA arrangements; or 4 periods: no trip limit, a low trip limit, a high trip limit, SETFIA arrangements) the estimated indices were very similar to when 6 period effects were estimated (Figure A3).

Because of the unrealistic year effects estimated when period effects were estimated an alternative approach was used. The landings multipliers for each period were applied to the individual tow data prior to standardization (on average this should convert the landings into total catch). This resulted in indices that were very similar to the indices used in the 2015 base model but which show a small decrease over the last 3 years (Figure A4). There is an upward trend since 2006 (Figure A4). The indices from the winter FIS show an increase followed by a decrease from 2008 to 2016 (Figure A5). This is different from the other 2018 indices but the change from 2008 to 2016 is the same as for the discard adjusted trawl CPUE indices (Figure A5). The September RAG meeting agreed that the discard adjusted trawl indices would be used as the base CPUE model.

The progressive addition of explanatory variables in the base model shows that the addition of latitude is the most important effect (Figure A6). The latitude effect is quite strong with the worst ling catches seen in the two most northern latitude classes (Figure A7). The indices are affected by the inclusion of the latitude effect because there is a shift to more southern latitudes since 1990 (Figure A8).

The inclusion of time-blocking (linked with the “top” three vessels) has a minor impact on the indices, raising them a little after about 2000 (Figure A9). Using the “top 2” vessels is very similar to using the “top 3” (Figure A9). However, using the “top 4” vessels is almost equivalent to linking the blocks with all vessels (Figure A9).

The day-or-night effects are very minimal (Figure A10). As expected, the tow duration is a strong effect with catch increasing with increasing time (Figure A11). The month effect peaks in June (Figure A12). The depth effects are strong with a peak at 500–600 m (Figure A13). Most vessel effects are between 0.5 and 3 with one vessel standing out with an effect of almost 6 (Figure A14).

Western trawl

The indices used in the base models in 2013 and 2015 are very similar to those derived from the 2018 dataset (Figure A15). However, they are not nearly as similar as those derived from the 2018 dataset when data from recent years are excluded to produce indices for a 2013 or 2015 assessment (Figure A16). As the same fitting methods were used in 2018 as in 2015 this suggested that the 2018 dataset had been changed since 2015. On investigation it was found that a small number of vessels had their callsigns changed in the 2018 dataset compared to the 2015 dataset and that this change has only been applied since 2000 (so that some vessels are now represented in the full dataset by more than one callsign). A fuller investigation found that correcting the callsigns for the small number of vessels made little difference to the indices. The difference between the 2015 and 2018 indices was eventually determined to be a much wider latitude range that was allowed in the 2015 model. The 2018 approach is preferred and the preliminary indices and the final indices (after correction of callsigns) are almost identical.

The indices from the winter FIS show a strong upward trend from 2008 to 2016 which is steeper than the preliminary CPUE indices (Figure A17).

The unstandardized indices have a similar shape to the standardised indices except that they show a less steep decline from 1997 and a stronger upward trend from 2005 to 2017 (Figure A18). The difference in the indices occurs when the duration effect is estimated (Figure A18). The duration effect has a strong impact because of a shift towards longer tow duration since about 2002 (Figure A19) and the expected increase in catch with longer tow duration (Figure A20).

The depth effect peaks at 500–550 m (Figure A21) but it is not nearly as strong as the depth effect in the east (see Figure A13). As for the east the day-or-night effects are minimal (Figure A22). Latitude is important (Figure A23) but not nearly as much as in the east (see Figure A7). The month effects are not very strong and peak in September and October (Figure A24) compared to June in the east (see Figure A12). Most vessel effects are between 0.5 and 2 with only one vessel higher at about 2.5 (Figure A25).

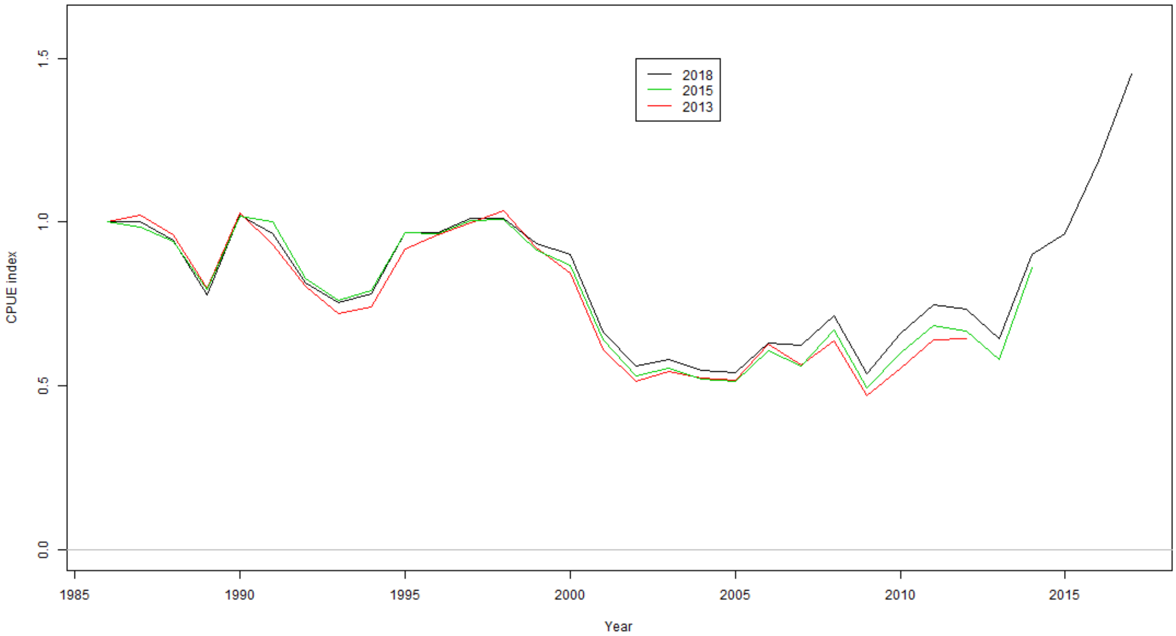

Figure A1: Eastern trawl CPUE indices estimated in the 2013 (base model), 2015 (base model), and 2018 assessments. In 2015 and 2018 period effects were estimated (see the main text).

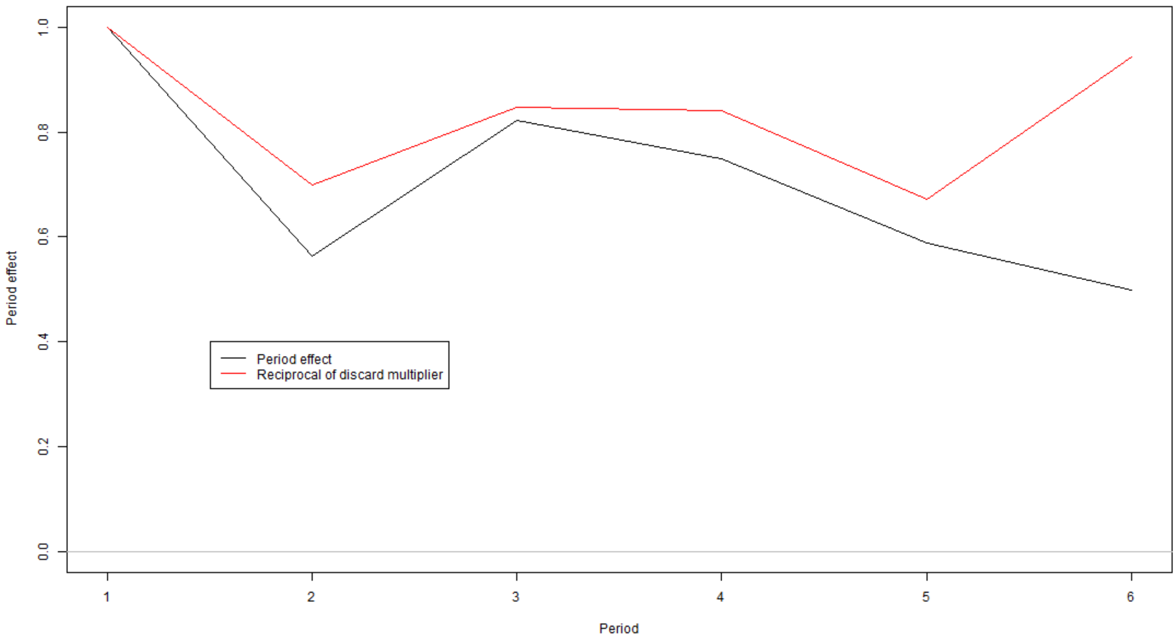

Figure A2: The estimated period effects for the eastern trawl CPUE and the reciprocal of the landings (discard) multipliers estimated from the ISMP data.

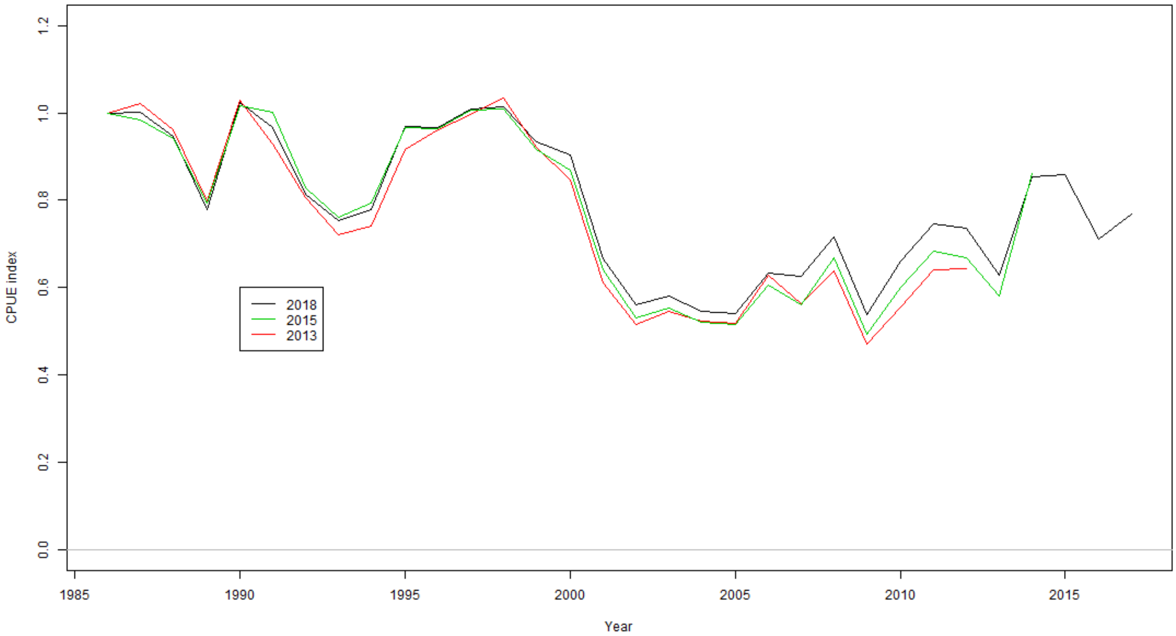

Figure A3: Eastern trawl CPUE comparing the base models in 2013 and 2015 with the 2018 model where the raw data were adjusted for discards before standardisation.

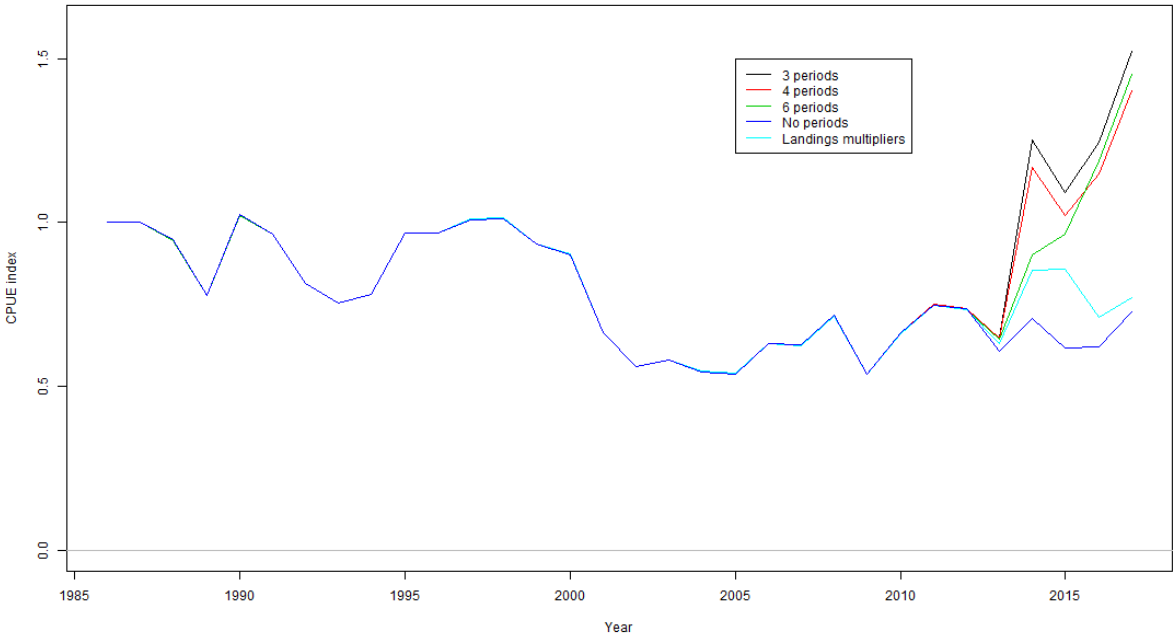

Figure A4: Eastern trawl CPUE comparing 2018 models where different numbers of period effects are estimated ("Periods"), an adjustment is made for discards ("Landing multipliers"), and no adjustment is made for discards and period effects are not estimated ("No periods").

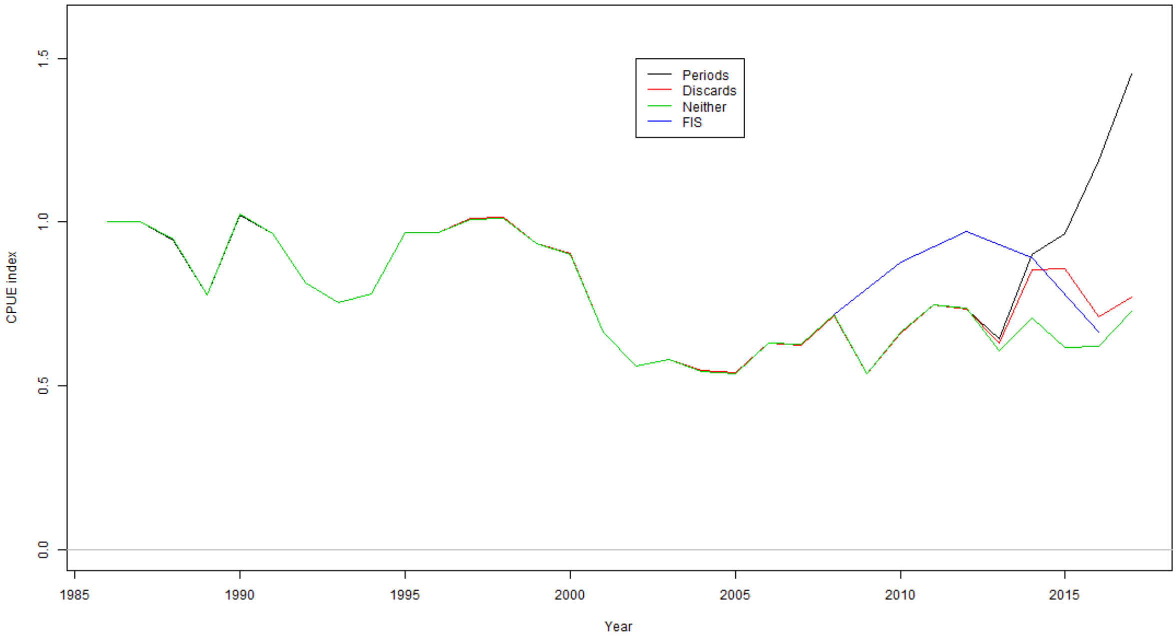

Figure A5: Eastern trawl CPUE comparing the 2018 models where period effects are estimated ("Periods"), an adjustment is made for discards ("Discards"), and no adjustment is made for discards and period effects are not estimated ("Neither"). The indices from the winter FIS are also shown.

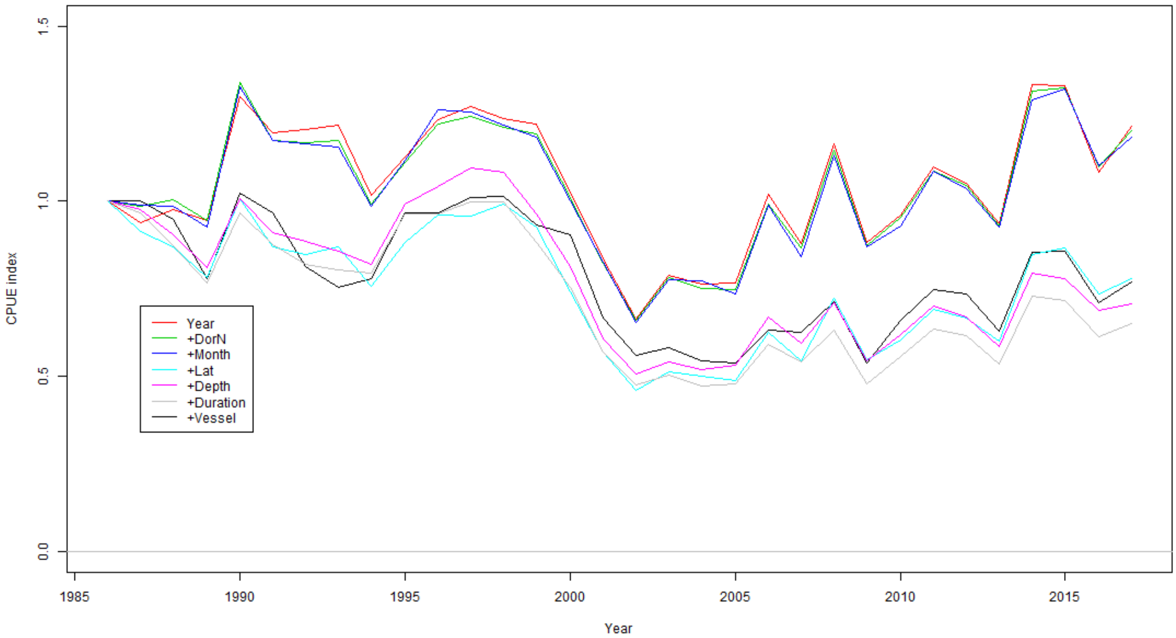

Figure A6: Eastern trawl CPUE indices resulting from the progressive addition of explanatory variables.

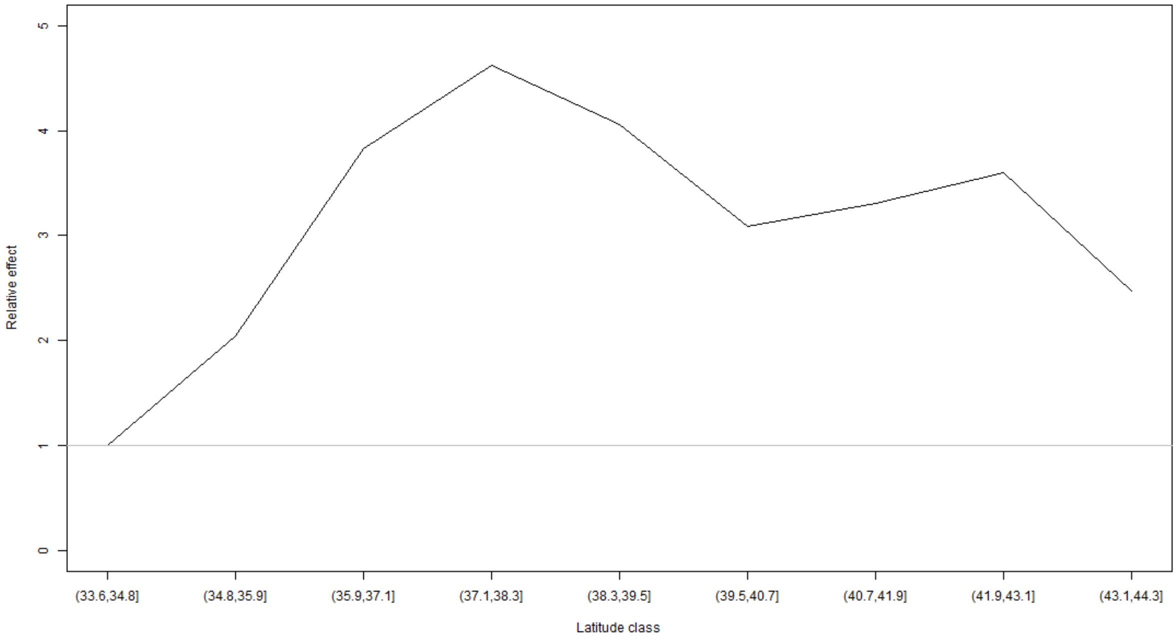

Figure A7: Eastern trawl CPUE, base model 2018: latitude effects.

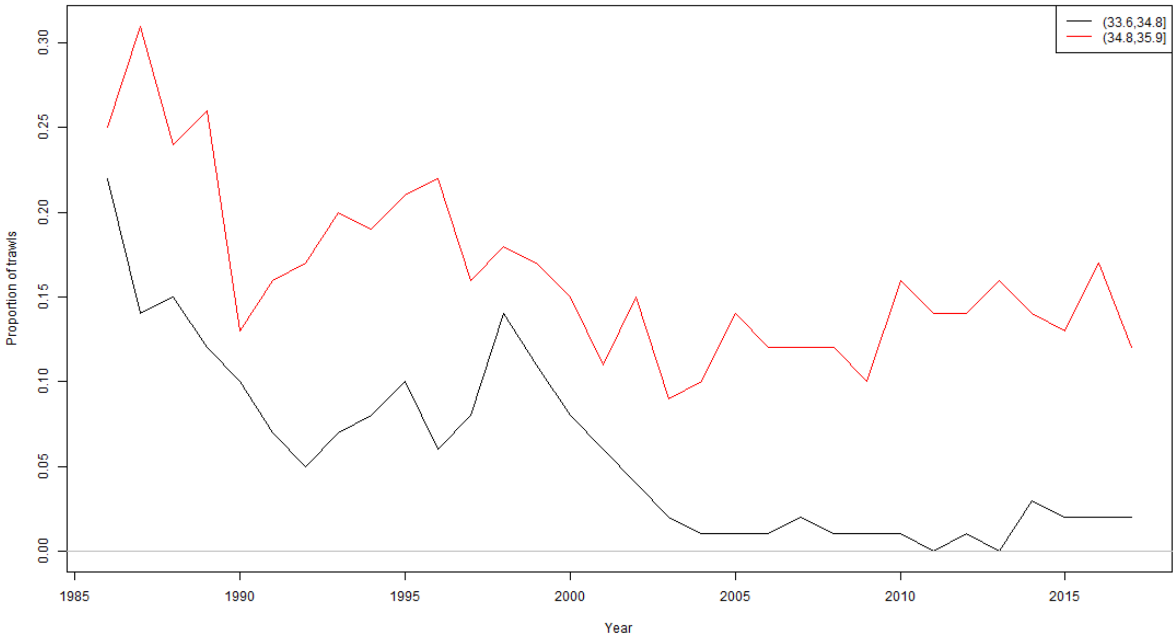

Figure A8: Eastern trawl CPUE: the proportion of ling tows each year for the two most northern latitude classes.

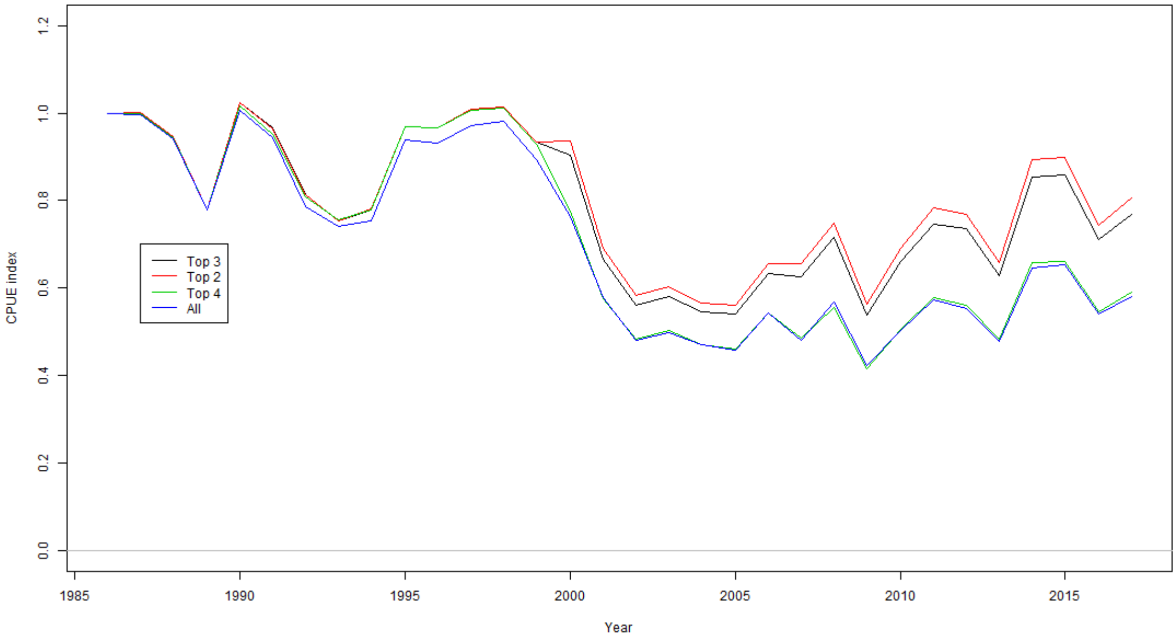

Figure A9: Eastern trawl CPUE, base model 2018 ("Top 3") compared with other treatments for the linking vessels (the "Top 2", the "Top 4", or using all vessels to link the time blocks).

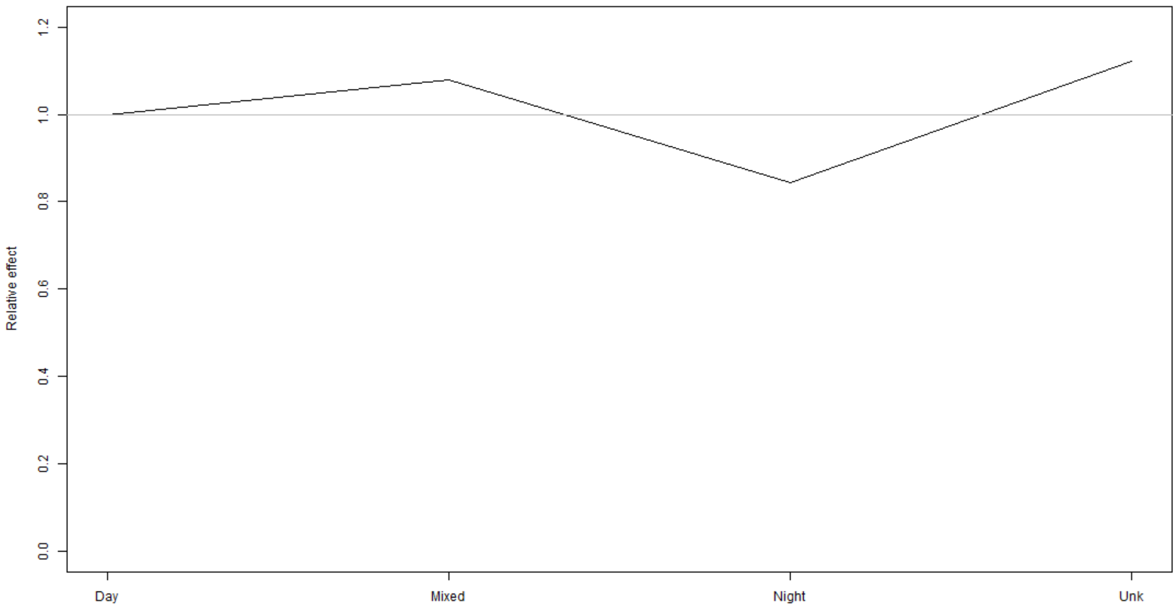

Figure A10: Eastern trawl CPUE, base model 2018: day-or-night effects for the timing of each trawl ("Unk" is unknown which represents a very small number of records).

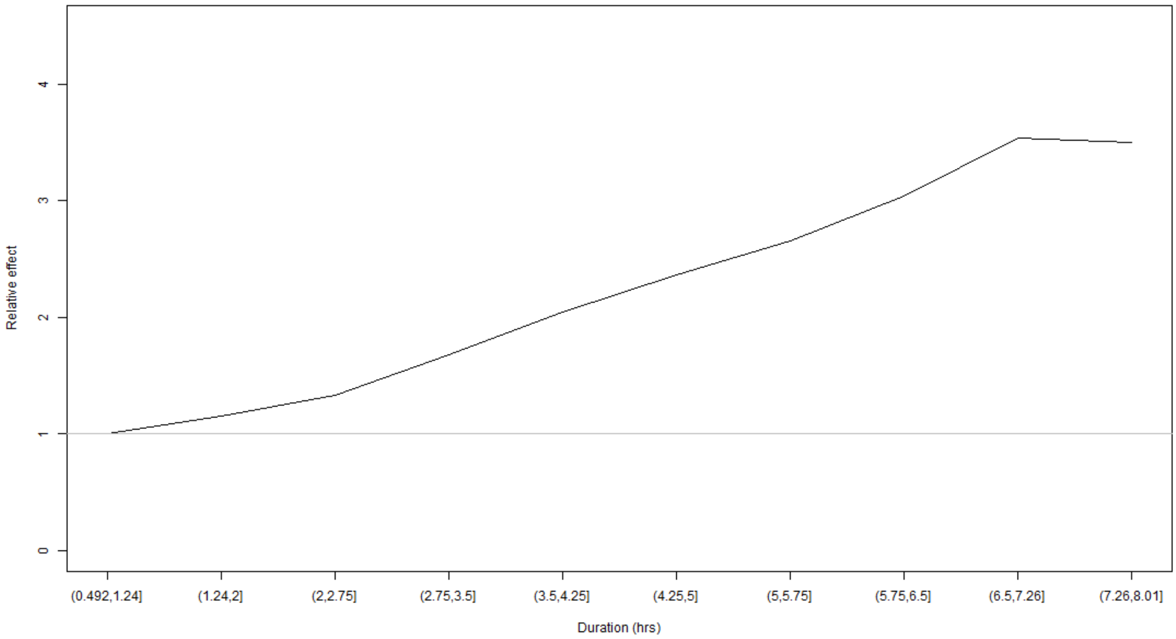

Figure A11: Eastern trawl CPUE, base model 2018: tow duration effects.

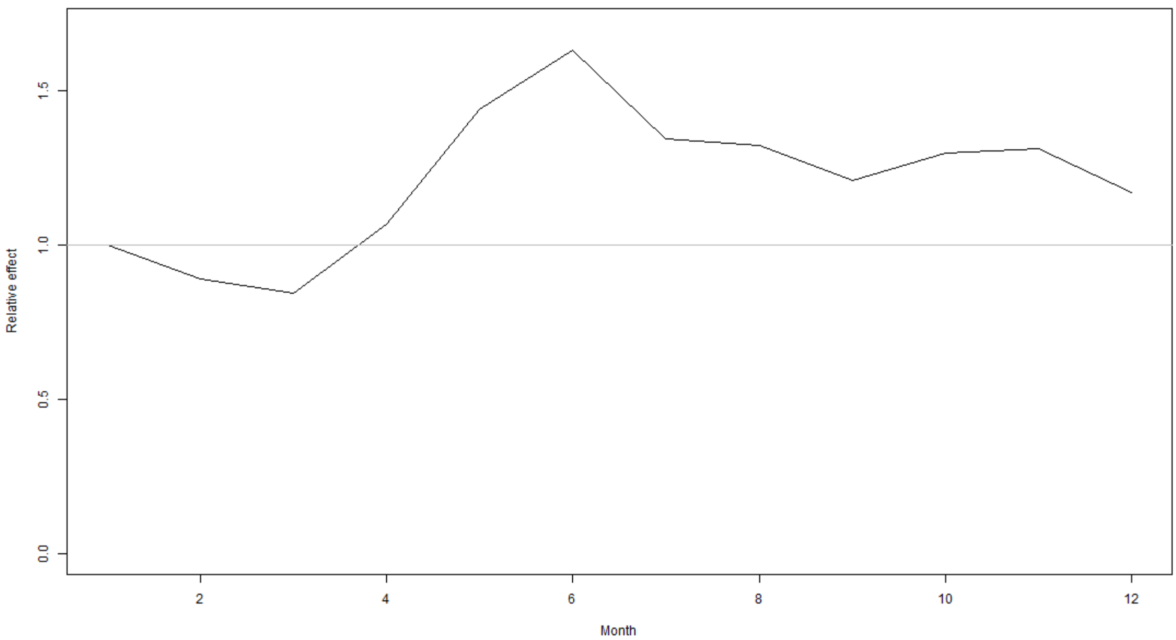

Figure A12: Eastern trawl CPUE, base model 2018: month effects.

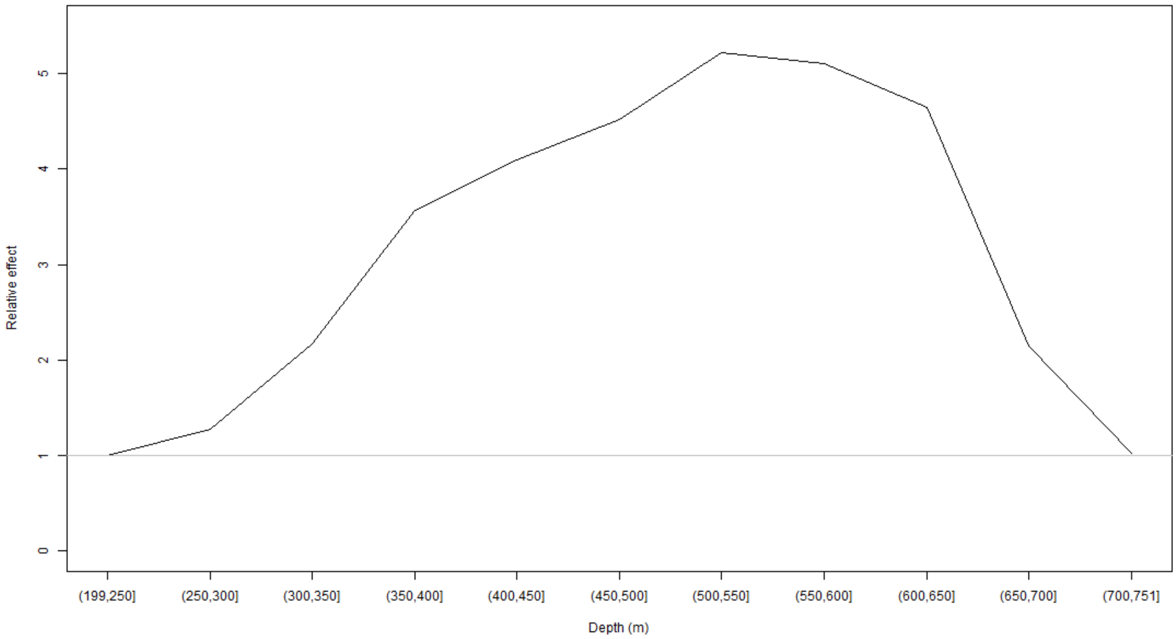

Figure A13: Eastern trawl CPUE, base model 2018: depth effects.

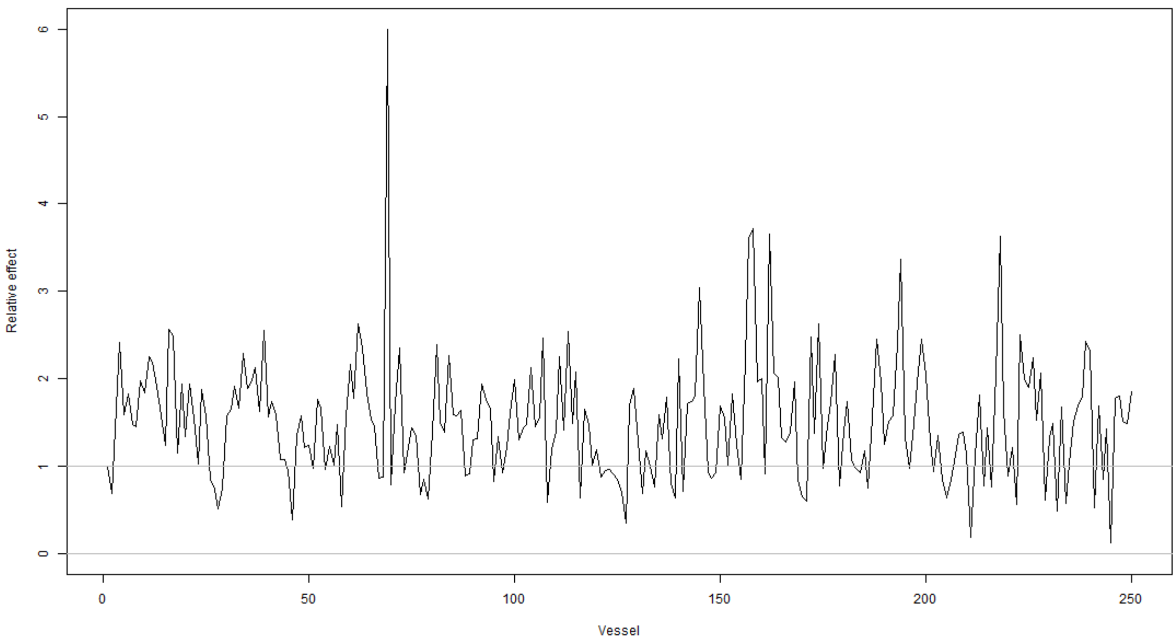

Figure A14: Eastern trawl CPUE, base model 2018: vessel effects. Other than the three vessels linking each time block, vessels are given a new code within each of the three time blocks (see text). (So some vessels have as many as three vessel effects estimated.)

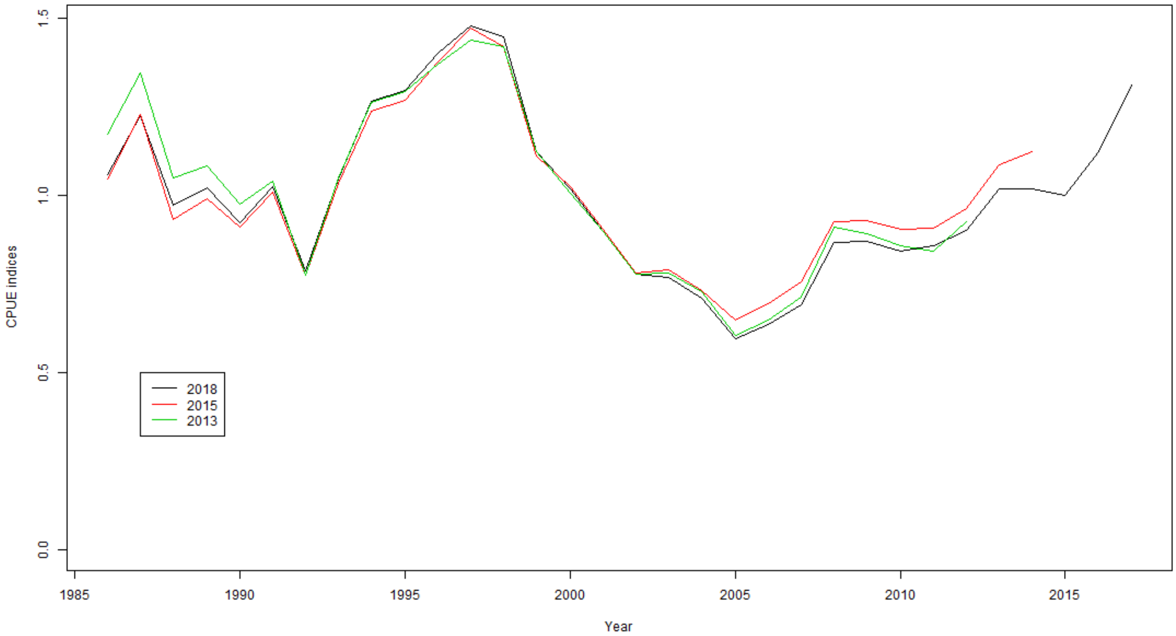

Figure A15: Western trawl CPUE comparing the 2013 (base model), 2015 (base model) with the 2018 standardised indices (preliminary model).

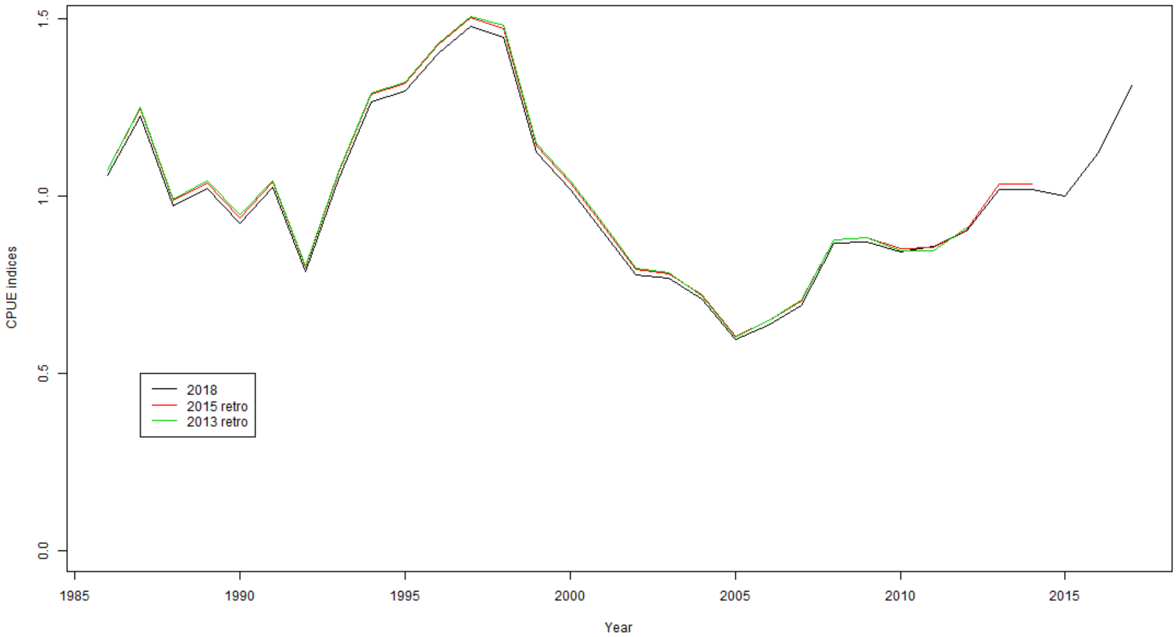

Figure A16: Western trawl CPUE indices for the 2018 data set: preliminary model ("2018"), data up to the end of 2014 fitted ("2015 retro"), and data up to the end of 2012 fitted ("2013 retro").

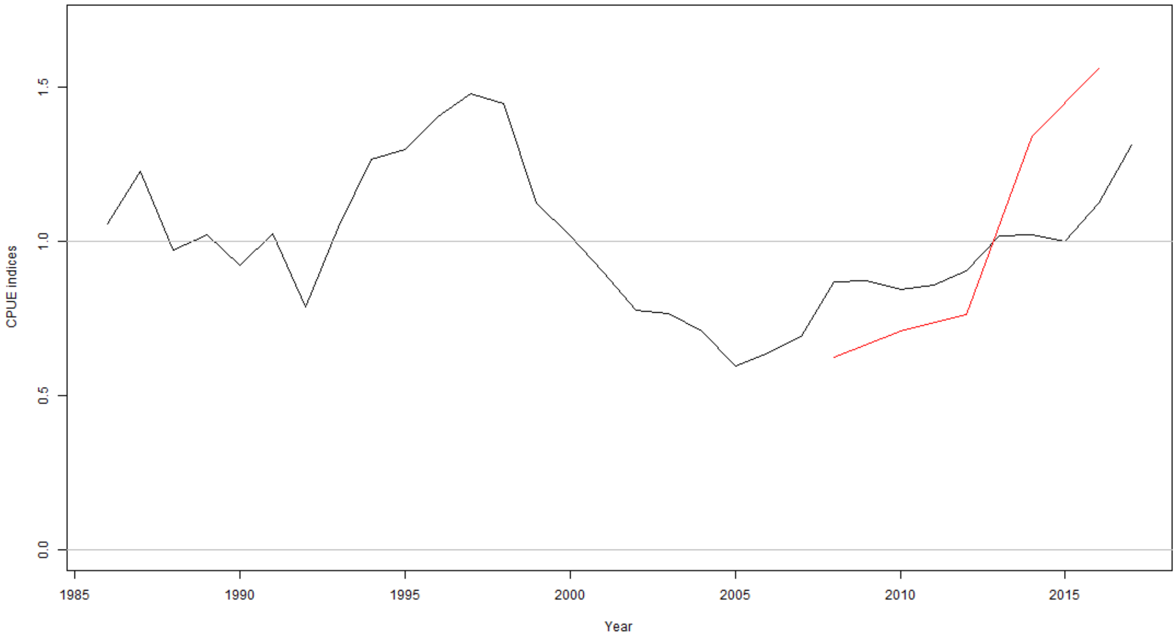

Figure A17: Western trawl CPUE comparing the 2018 preliminary model with the winter FIS indices.

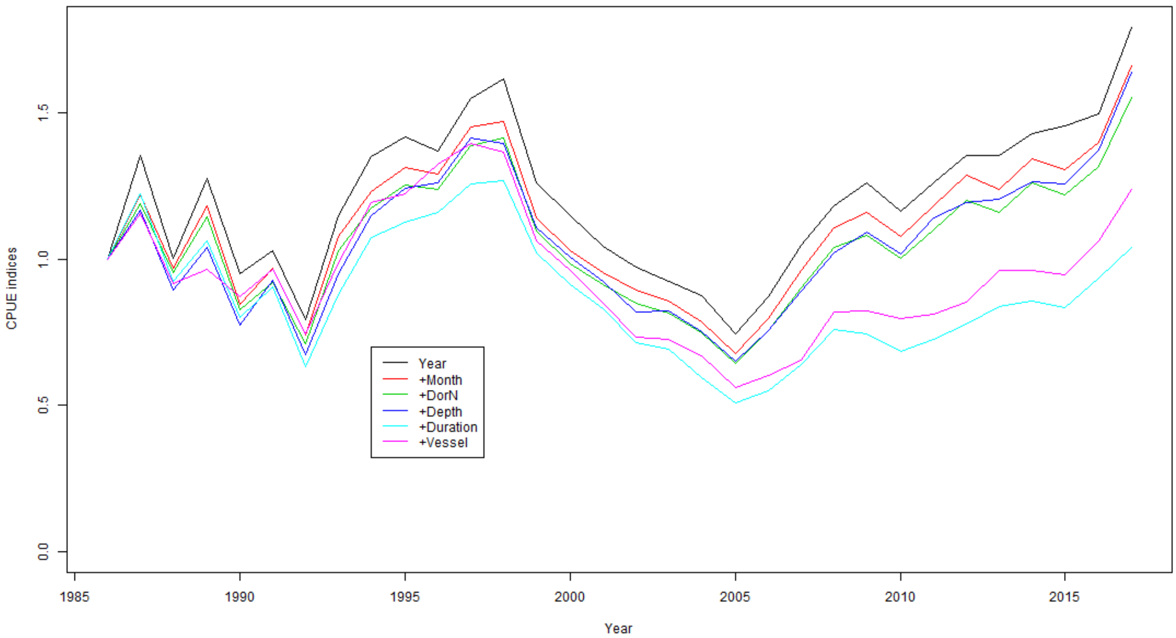

Figure A18: Western trawl CPUE indices resulting from the progressive addition of explanatory variables.

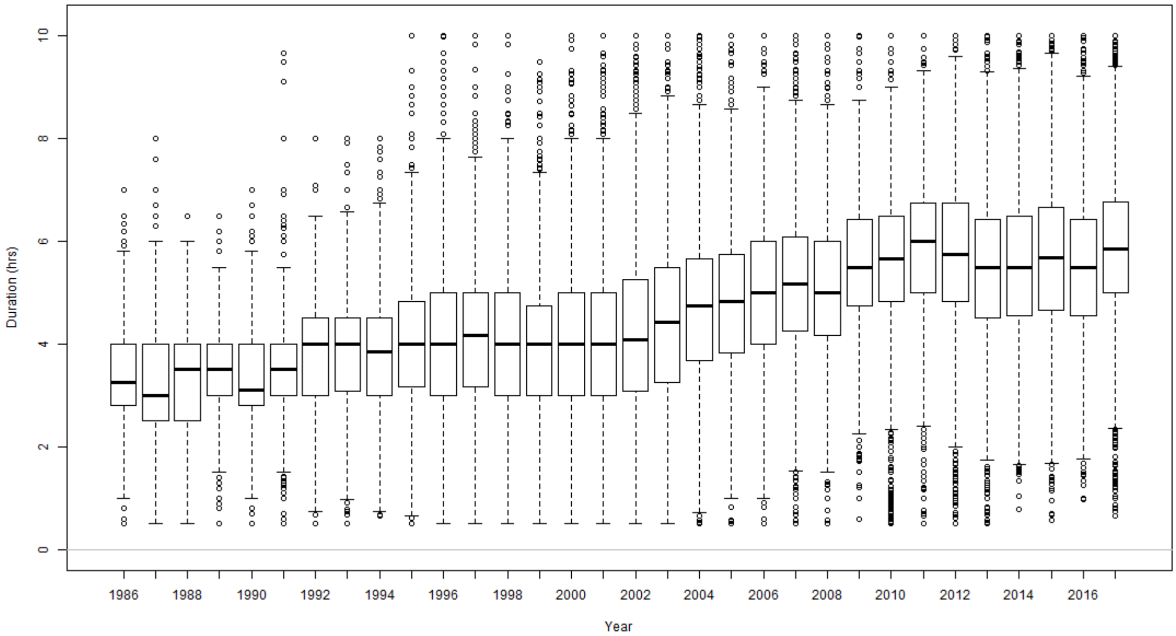

Figure A19: Western trawl CPUE: box and whiskers plots of tow duration each year. The horizontal line is the median and the box covers the middle 50% of the distribution.

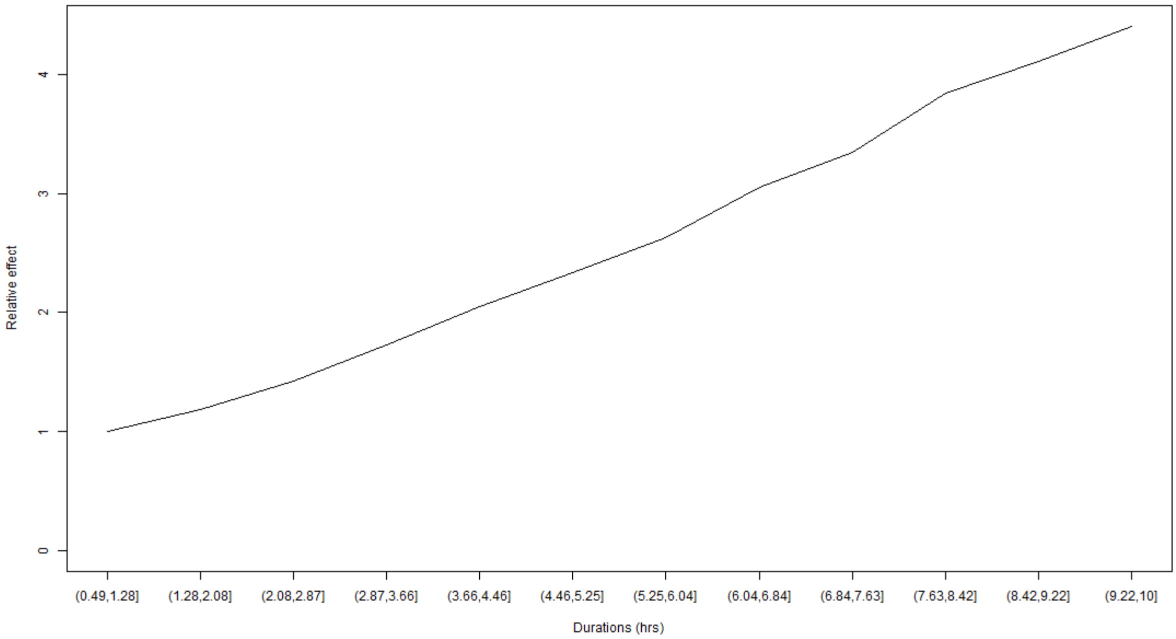

Figure A20: Western trawl CPUE preliminary model: tow duration effects.

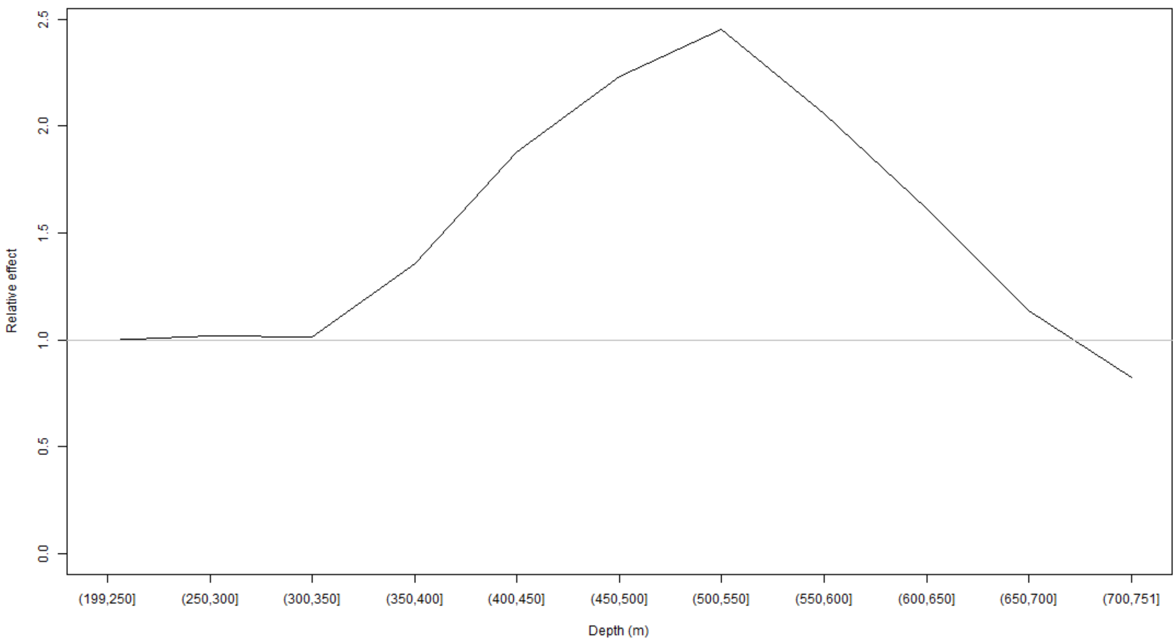

Figure A21: Western trawl CPUE preliminary model: depth effects from 200 to 750 m.

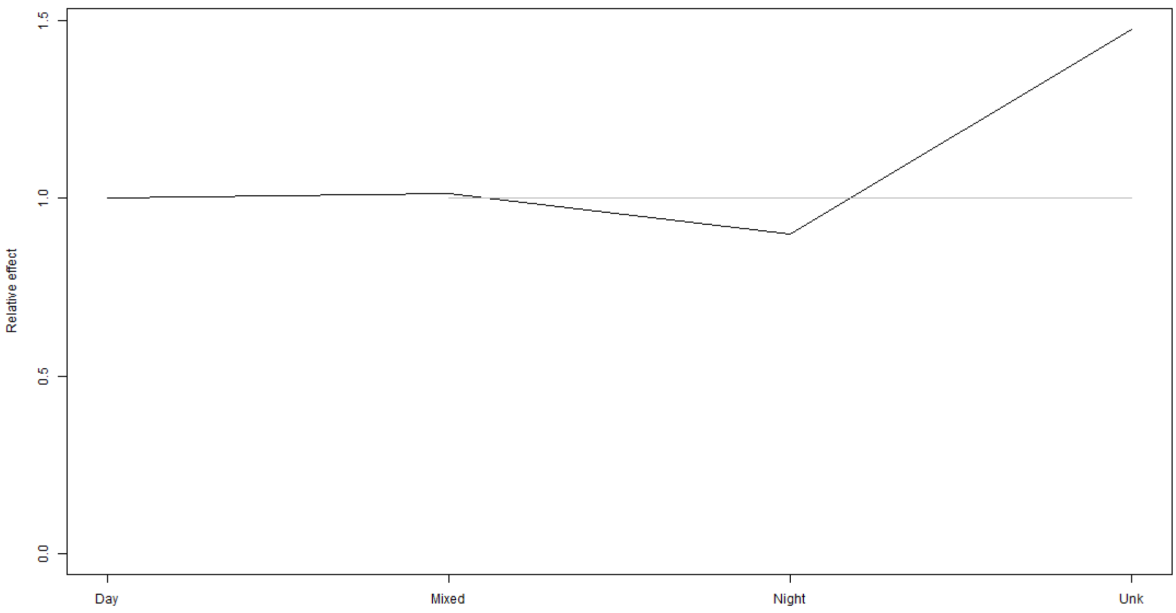

Figure A22: Western trawl CPUE preliminary model: day-or-night effects for the timing of each trawl shot (“Unk” is unknown which represents a very small number of records).

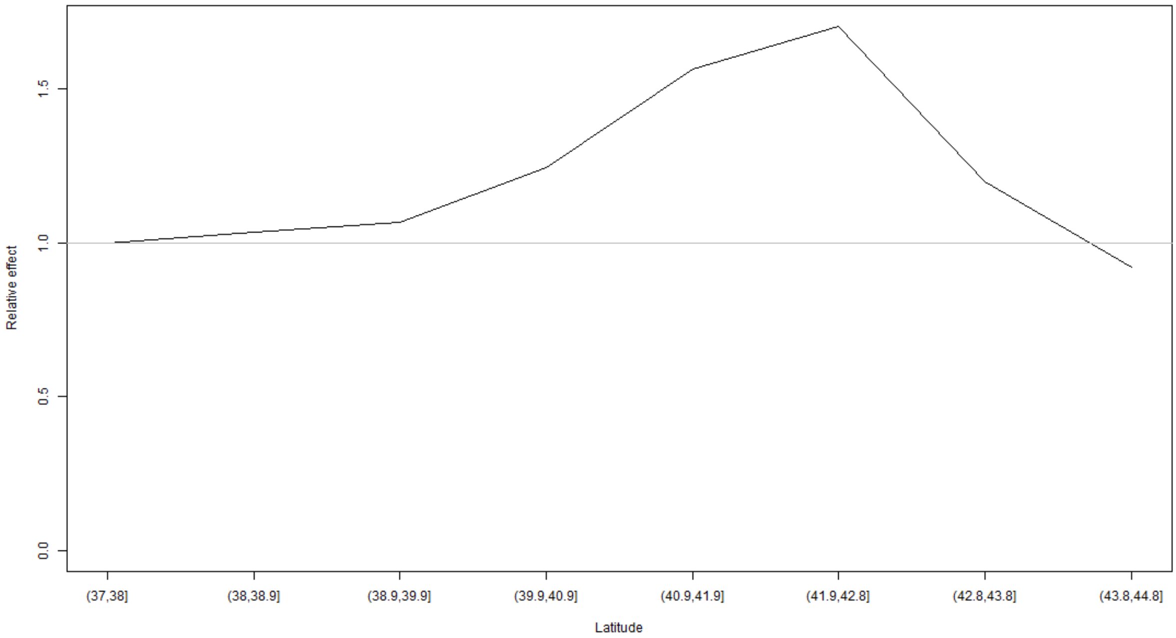

Figure A23: Western trawl CPUE preliminary model: latitude effects (degrees south).

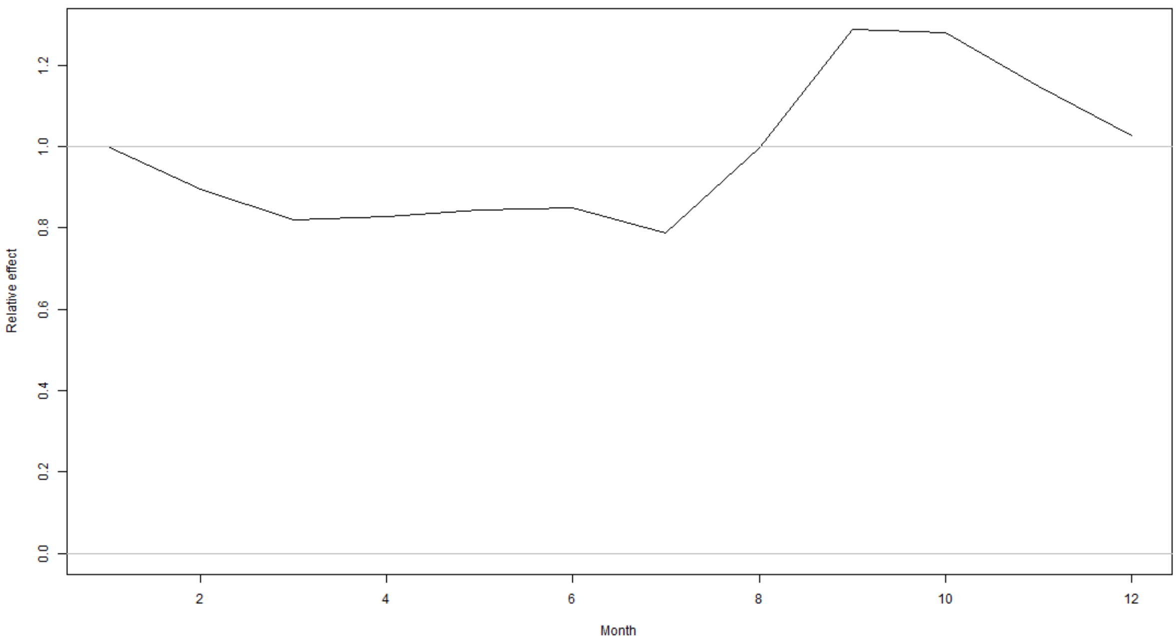

Figure A24: Western trawl CPUE preliminary model: month effects.

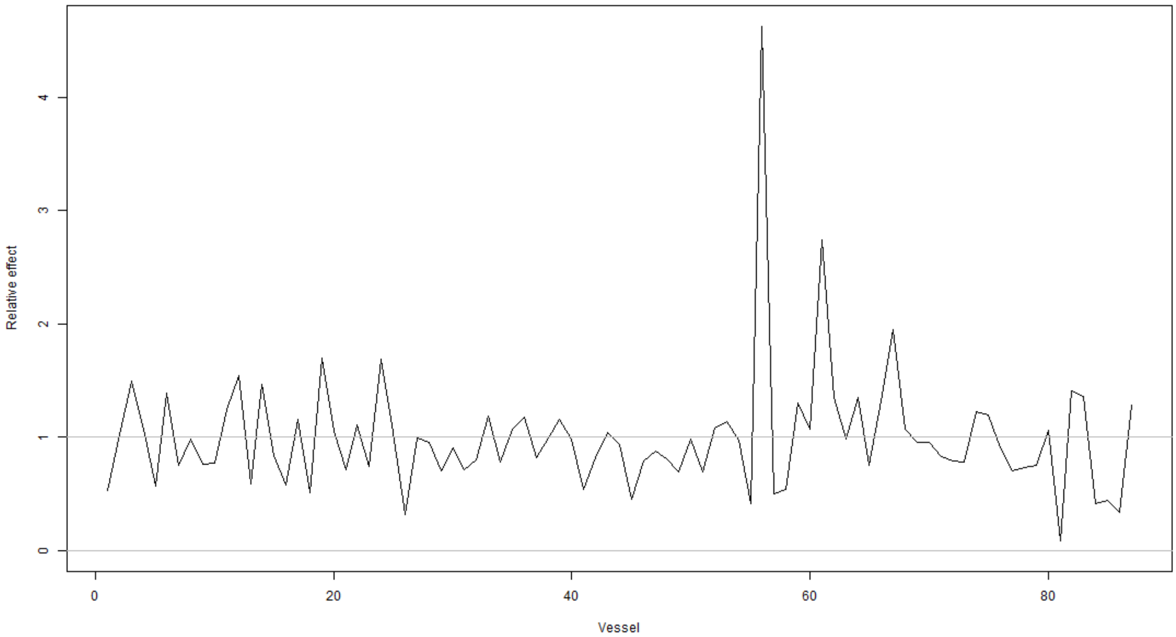

Figure A25: Western trawl CPUE preliminary model: vessel effects. Time blocking was not used so each vessel had a single effect estimated. The number of vessels is larger than it should be as some vessels are represented by multiple callsigns in the 2018 dataset (this is why the model is preliminary).

Appendix B: MPD diagnostics including fits to biomass indices, length frequencies, age frequencies, and marginal age distributions

Eastern reference model

A full set of MPD fits is given below for the reference model. This was the model originally chosen as the base model at the first SERAG meeting but at the second meeting the base model was changed to the reference model with M=0.23. The MPD fits to the data for the two models will be very similar and often identical. The purpose of looking at the fits is to make sure that the best fit (which is what the MPD fit is) is not so bad that one would be concerned about the model.

The fit to the trawl CPUE indices is excellent (Figure B1). The fit to the FIS biomass indices and length frequencies are acceptable (Figures B2-B3). All of the fits to commercial length and age frequencies are acceptable (Figures B4-B11). It is impossible to produce concise and easily interpreted fits for conditional age-at-length data. As a proxy, for each year within fishery for which conditional age-at-length data were available the predicted age frequencies from the model were compared with the marginal age frequencies. While the model is not fitting to these data it is clear that the predicted age frequencies closely follow the marginal age frequencies (Figures B12-B16)

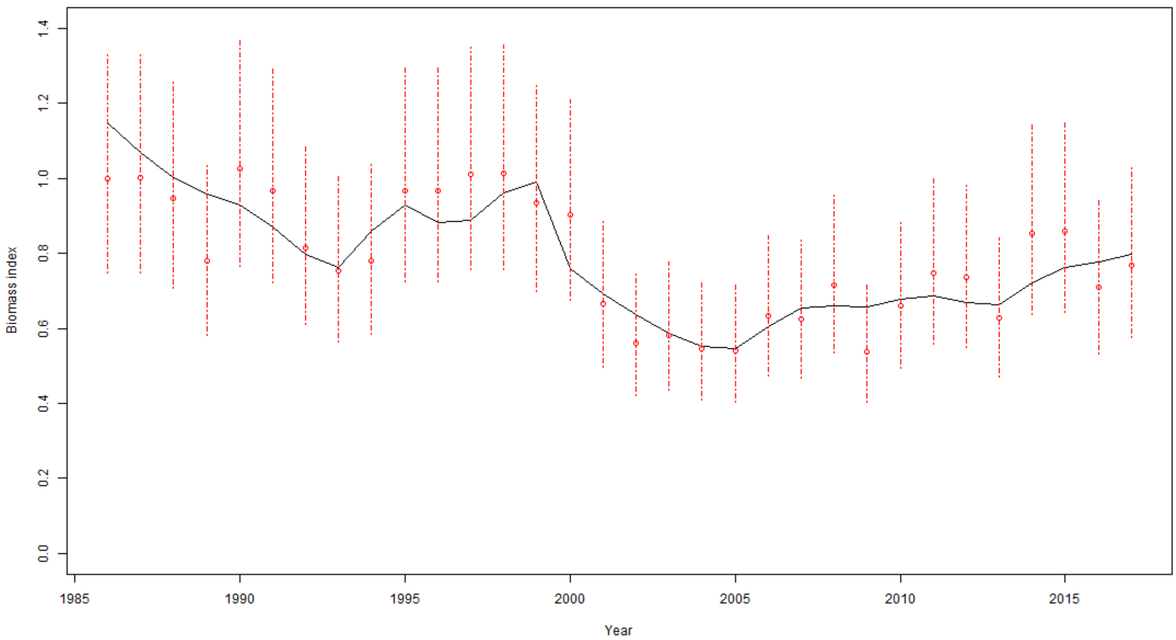

Figure B1: Eastern stock: reference model MPD fit (solid line) to the trawl fishery CPUE indices (red points with 95% CIs).

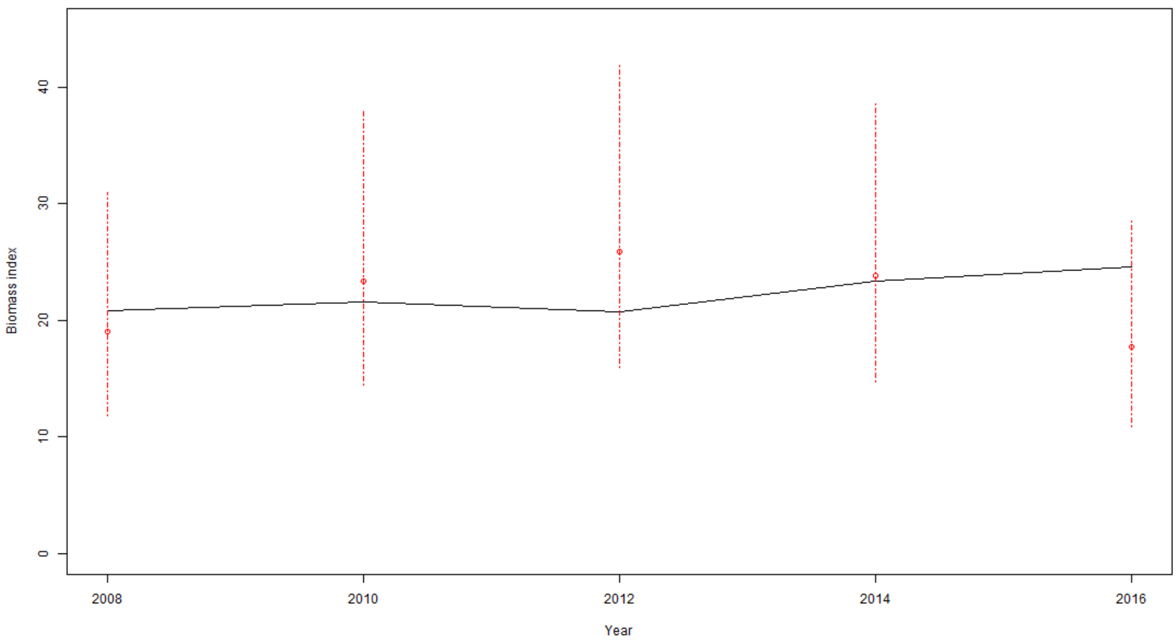

Figure B2: Eastern stock: reference model MPD fit (solid line) to the FIS indices (red points with 95% CIs).

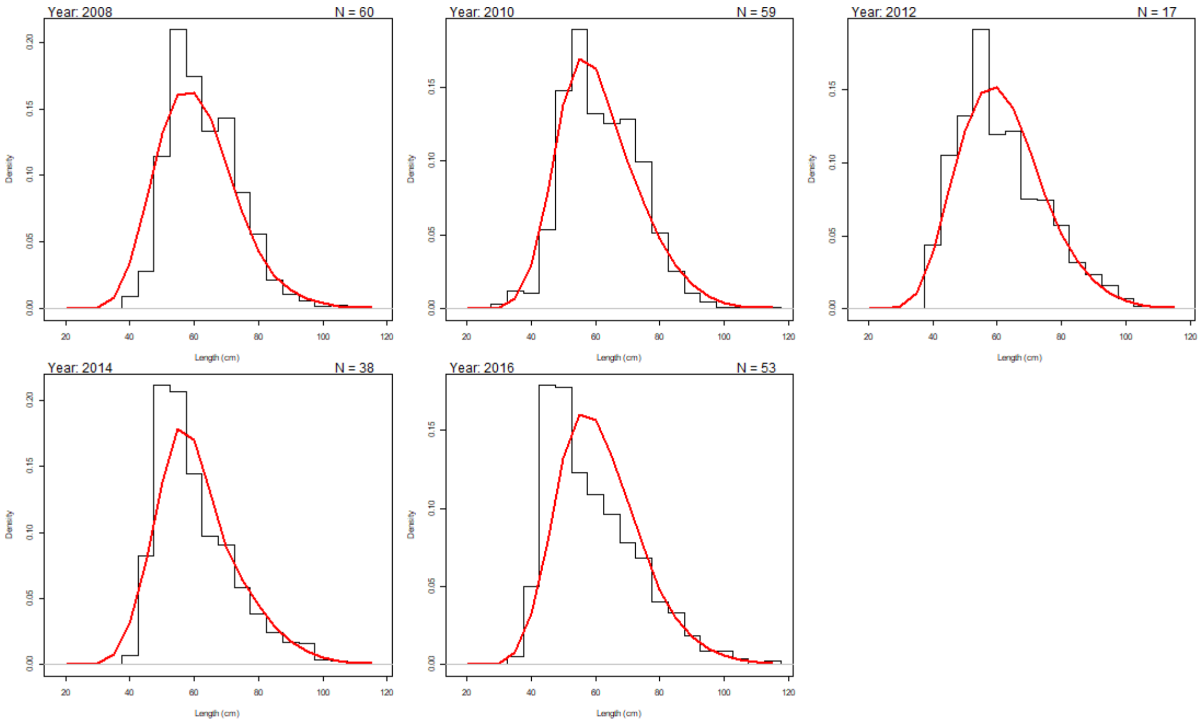

Figure B3: Eastern stock: reference model MPD fit (red curves) to the FIS length frequencies (histograms). N is the effective sample size in the model.

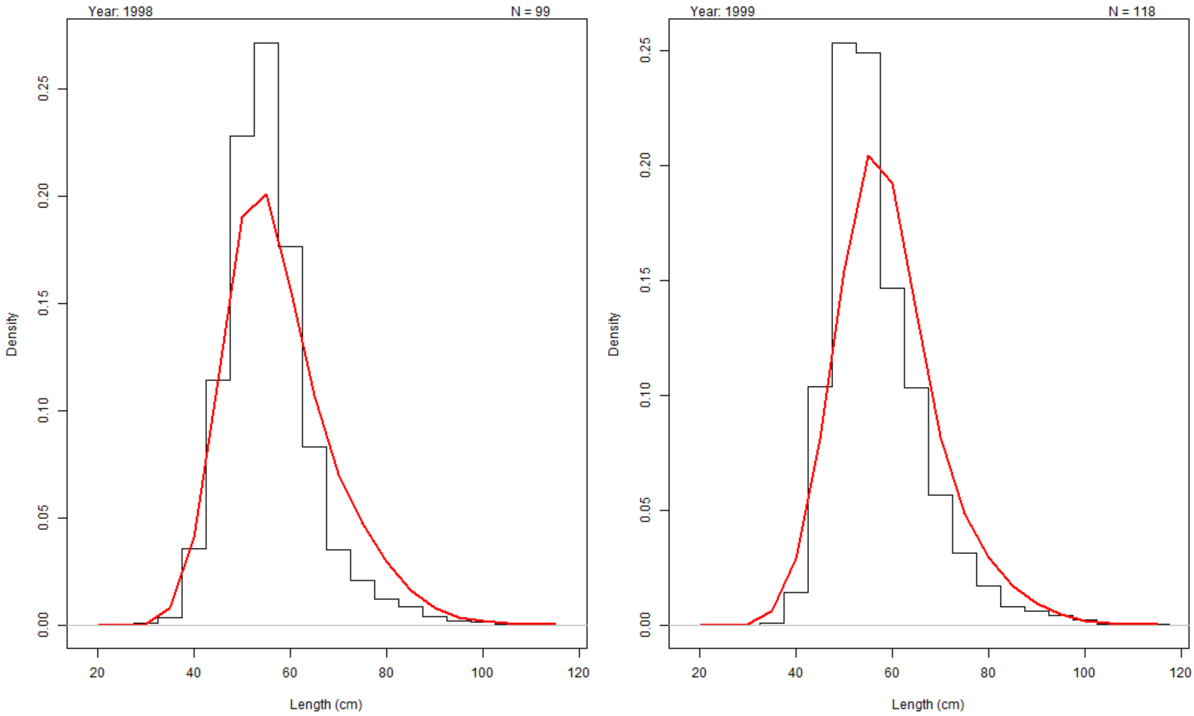

Figure B4: Eastern stock: reference model MPD fit (red curves) to the trawl fishery length frequencies (histograms) in the first fishing block (before 2000). N is the effective sample size in the model.

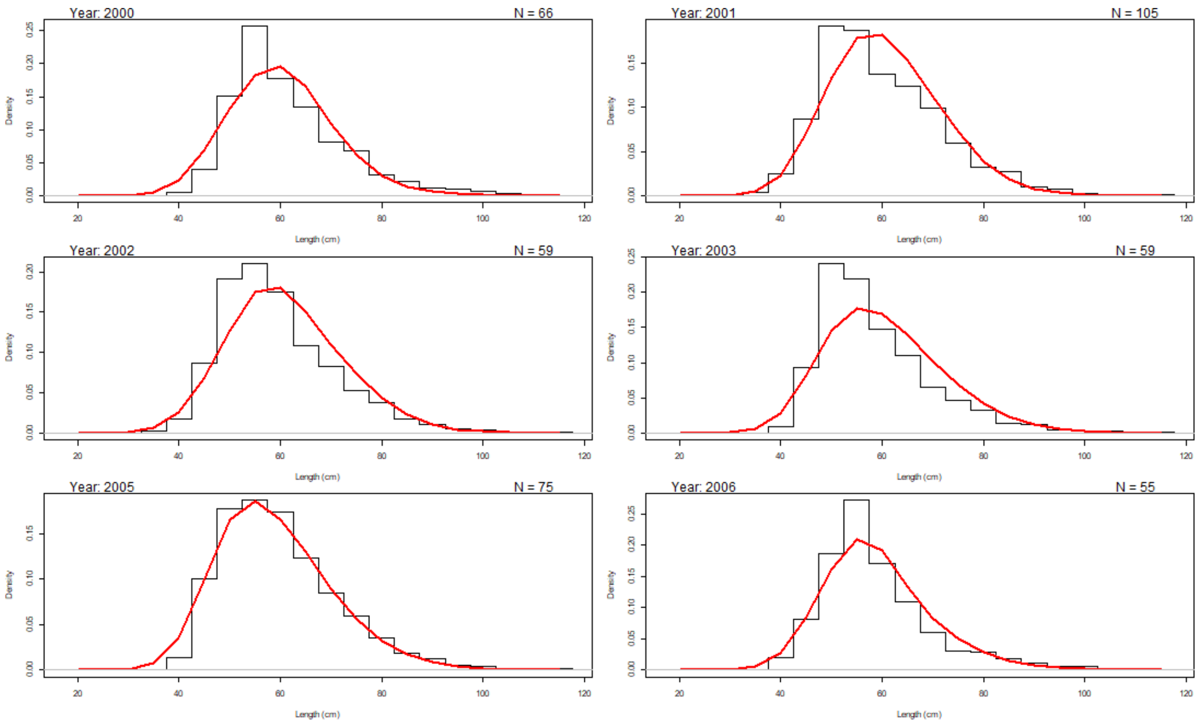

Figure B5: Eastern stock: reference model MPD fit (red curves) to the trawl fishery length frequencies (histograms) in the second fishing block (2000-2006 inclusive). N is the effective sample size in the model.

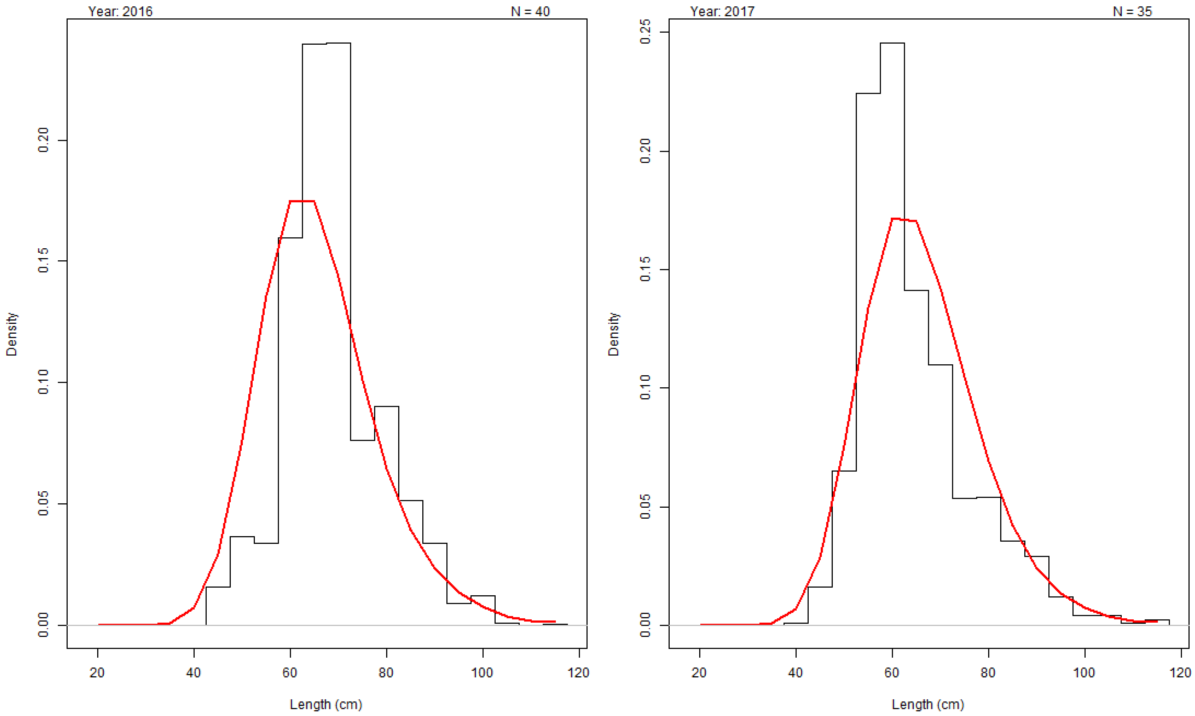

Figure B6: Eastern stock: reference model MPD fit (red curves) to the trawl fishery length frequencies (histograms) in the last fishing block (after 2006). N is the effective sample size in the model.

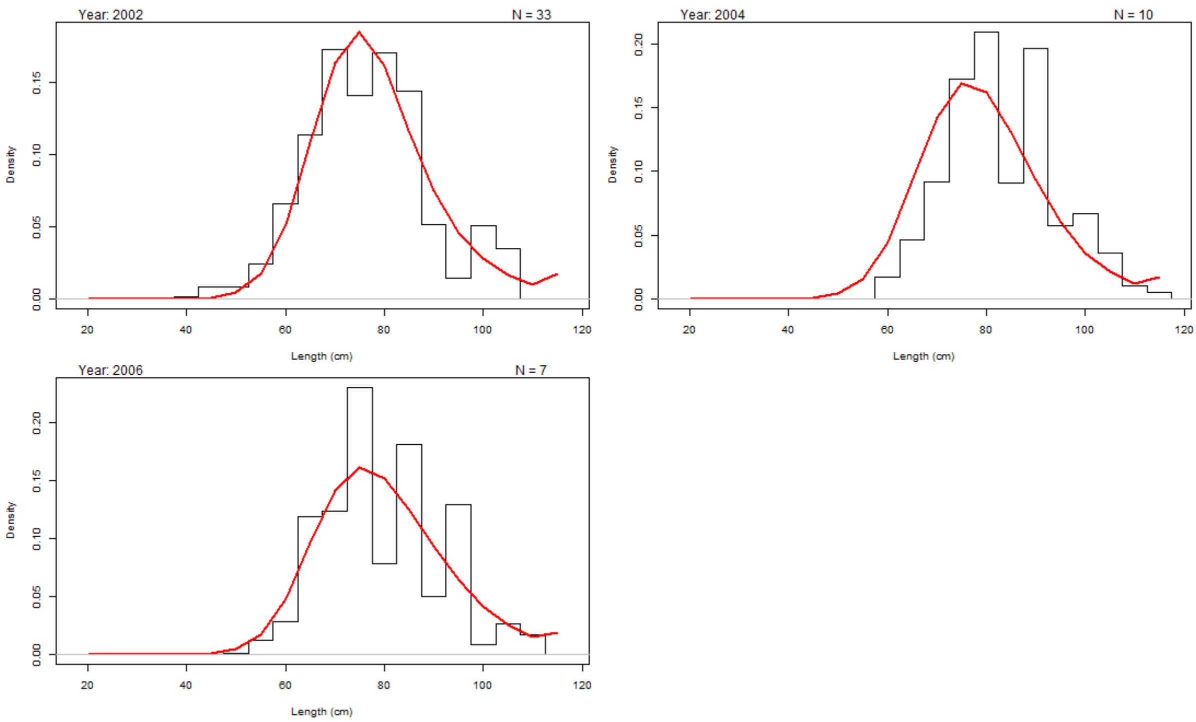

Figure B7: Eastern stock: reference model MPD fit (red curves) to the non-trawl fishery length frequencies (histograms) sampled at the port. N is the effective sample size in the model.

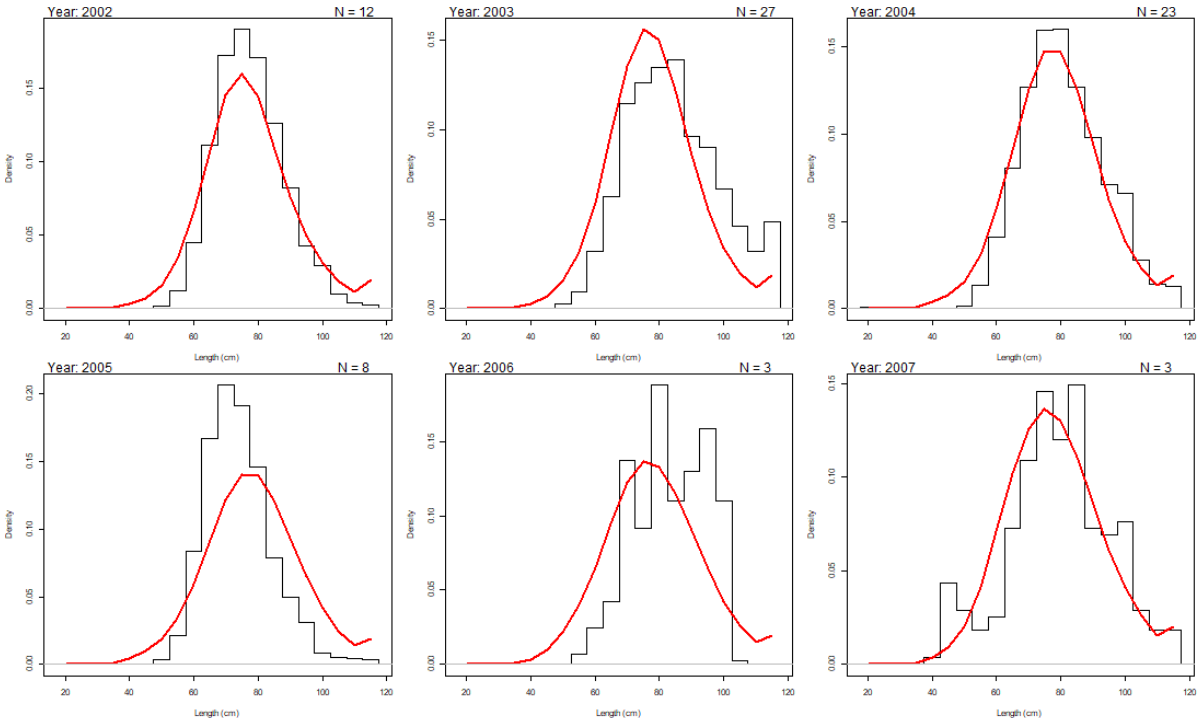

Figure B8: Eastern stock: reference model MPD fit (red curves) to the non-trawl fishery length frequencies (histograms) sampled at sea (2002-2007 inclusive). N is the effective sample size in the model.

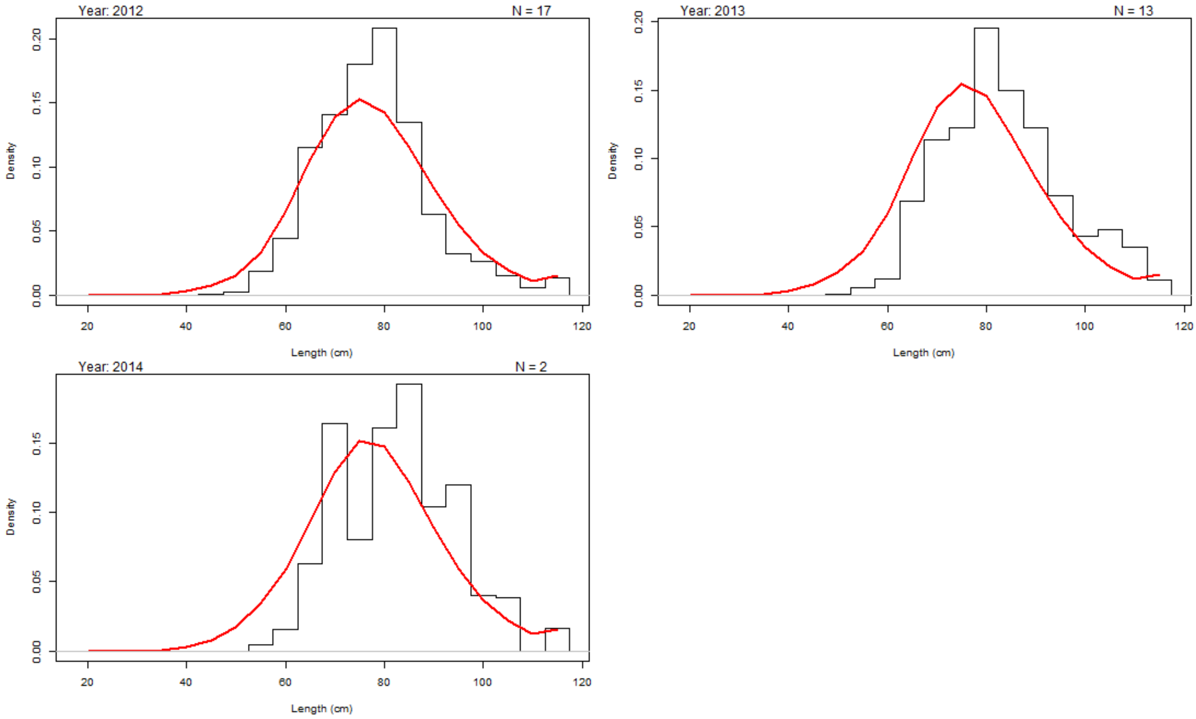

Figure B9: Eastern stock: reference model MPD fit (red curves) to the non-trawl fishery length frequencies (histograms) sampled at sea (2012-2014 inclusive). N is the effective sample size in the model.

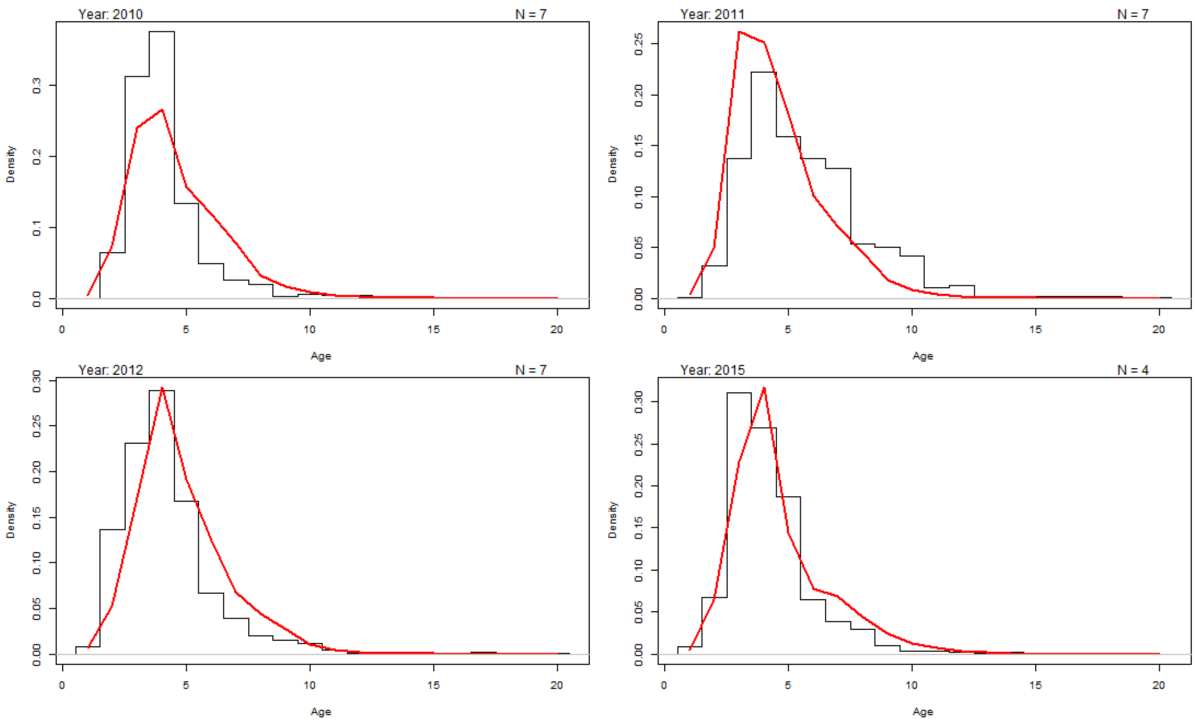

Figure B10: Eastern stock: reference model MPD fit (red curves) to the trawl fishery age frequencies (histograms) fitted in the model. N is the effective sample size in the model.

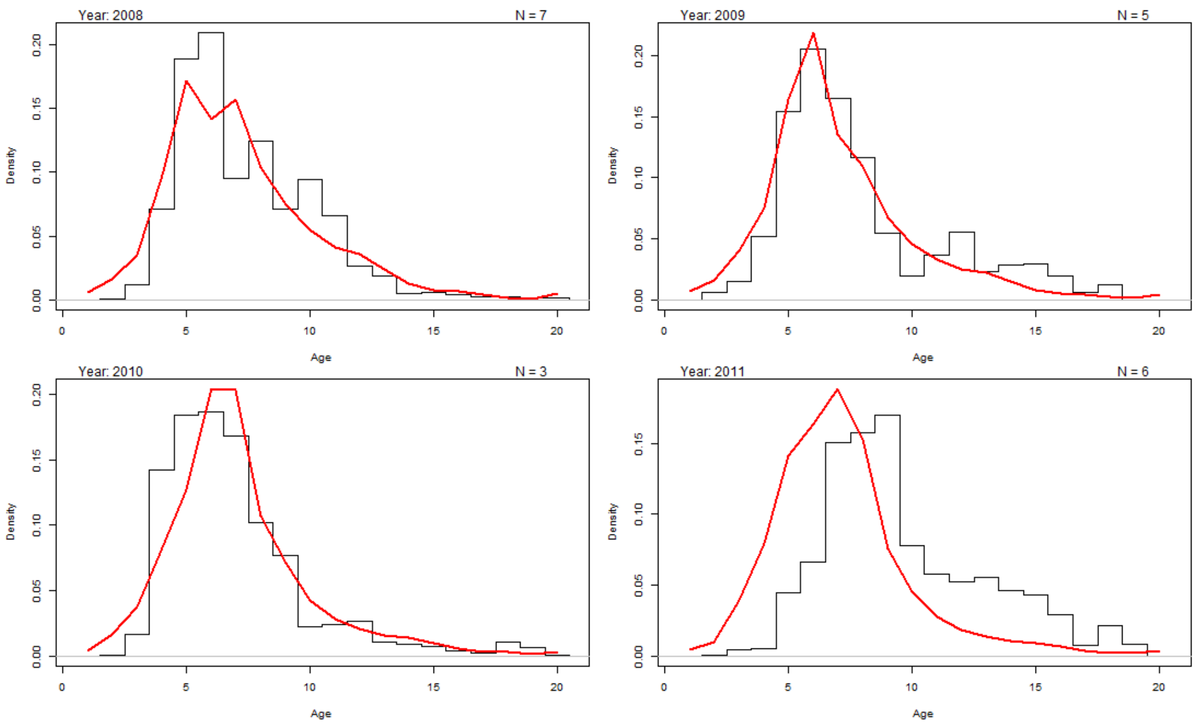

Figure B11: Eastern stock: reference model MPD fit (red curves) to the non-trawl fishery age frequencies (histograms) fitted in the model. N is the effective sample size in the model.

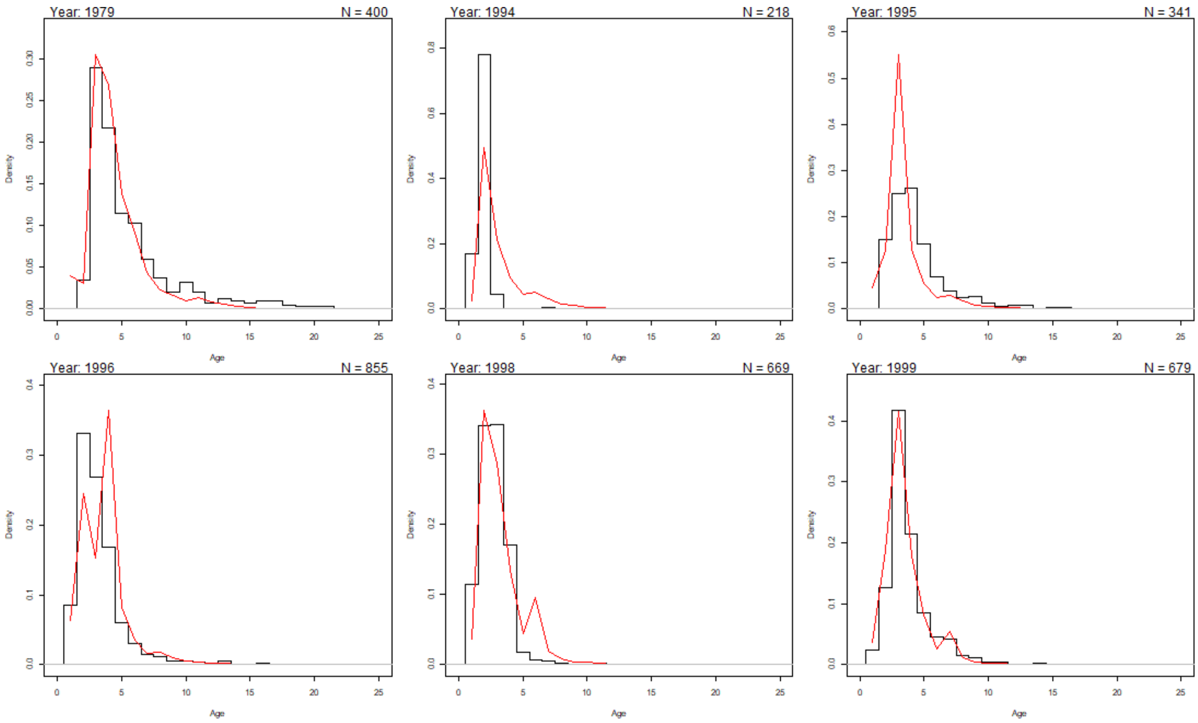

Figure B12: Eastern stock: reference model MPD predicted age frequencies (red curves) compared to the trawl fishery age frequencies (histograms) for all aged fish in the eastern zone in the given year in the first fishing block. N is the total number of aged fish in the given year (sexed and unsexed).

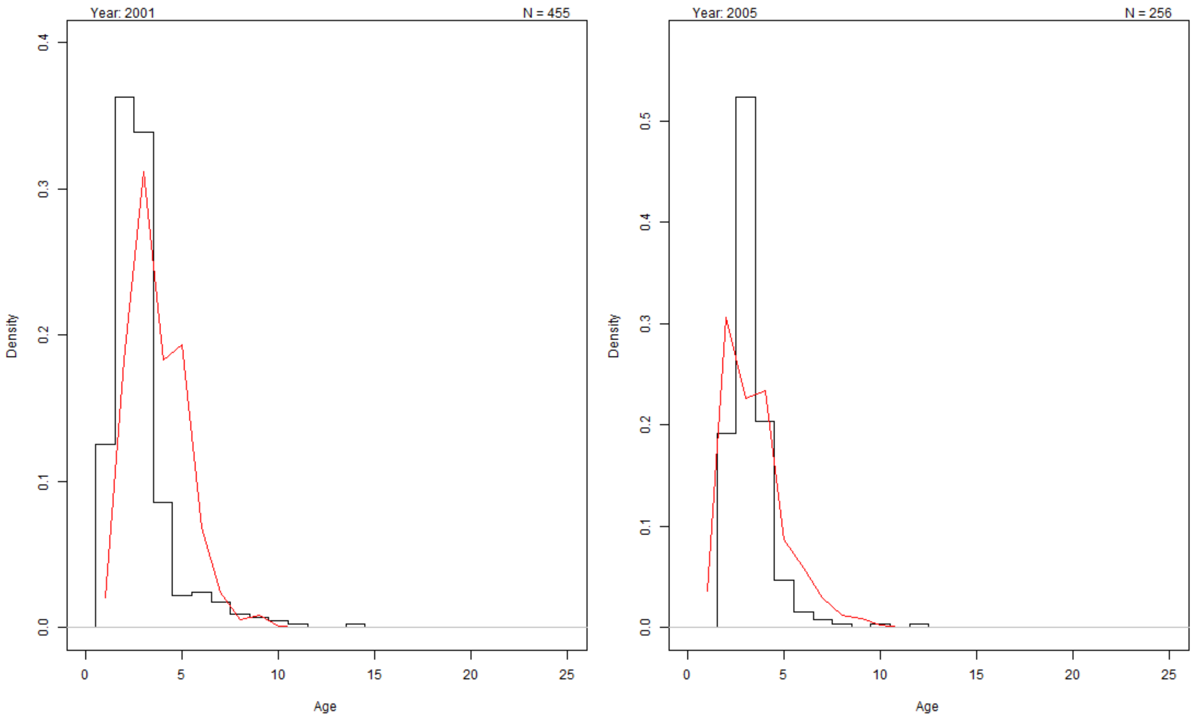

Figure B13: Eastern stock: reference model MPD predicted age frequencies (red curves) compared to the trawl fishery age frequencies (histograms) for all aged fish in the eastern zone in the given year in the second fishing block. N is the total number of aged fish in the given year (sexed and unsexed).

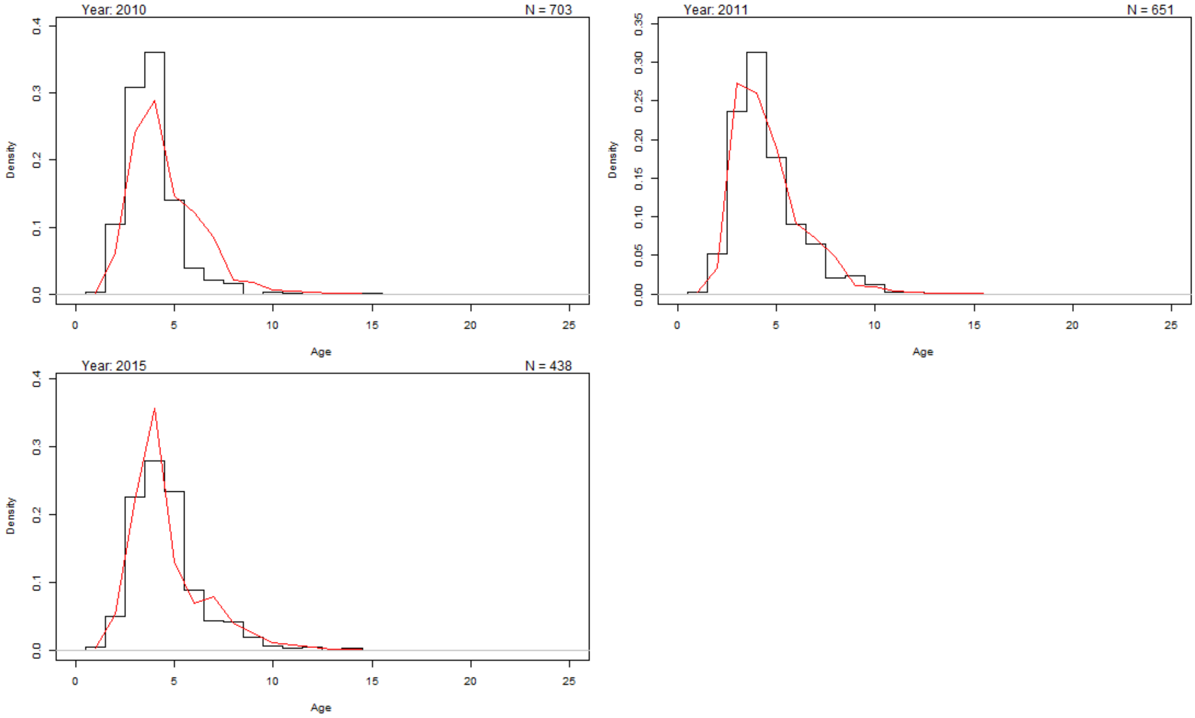

Figure B14: Eastern stock: reference model MPD predicted age frequencies (red curves) compared to the trawl fishery age frequencies (histograms) for all aged fish in the eastern zone in the given year in the last fishing block. N is the total number of aged fish in the given year (sexed and unsexed).

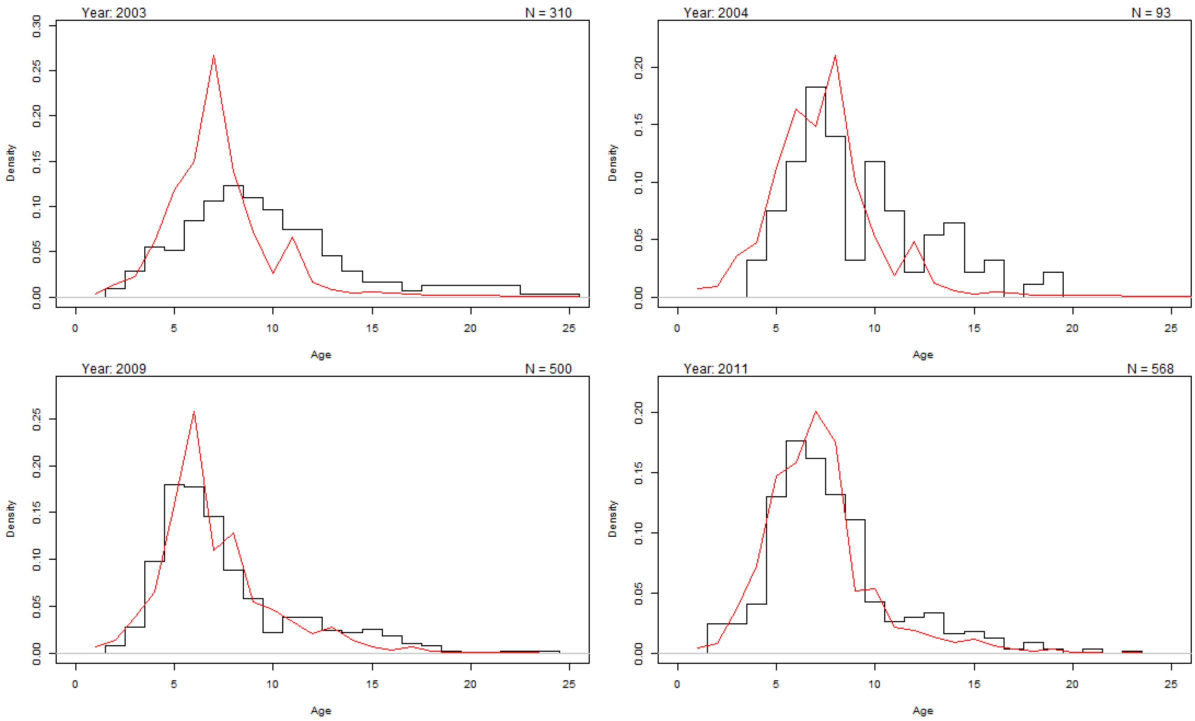

Figure B15: Eastern stock: reference model MPD predicted age frequencies (red curves) compared to the non-trawl fishery age frequencies (histograms) for all aged fish in the eastern zone in the given year (2003, 2004, 2009, and 2011). N is the total number of aged fish in the given year (sexed and unsexed).

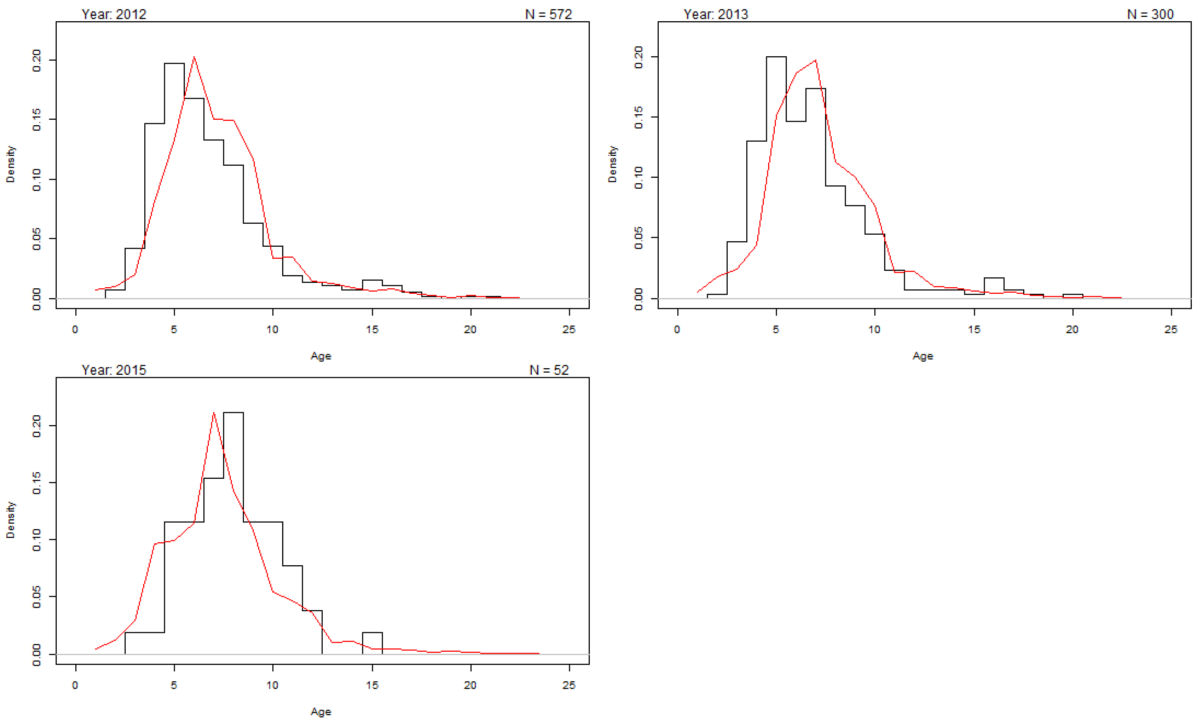

Figure B16: Eastern stock: reference model MPD predicted age frequencies (red curves) compared to the non-trawl fishery age frequencies (histograms) for all aged fish in the eastern zone in the given year (2012, 2013, and 2015). N is the total number of aged fish in the given year (sexed and unsexed).

Western base model

A full set of MPD fits is given below for the base model. The purpose of looking at the fits is to make sure that the best fit (which is what the MPD fit is) is not so bad that one would be concerned about the model.

The fit to the trawl CPUE indices is just adequate (Figure B17). There is a run of 6 positive residuals followed by a run of 8 negative residuals (Figure B17). This strongly suggests that the errors are correlated rather than being independent as is assumed in the model. However, it is a similar fit to previous years and there is little to be done about it. The fit is improved in the most recent years by estimating 2 more YCS than were fitted in the 2015 assessment (Figure B17).

The fit to the FIS biomass indices and length frequencies are acceptable (Figures B18-B19). All of the fits to commercial length and age frequencies are acceptable (Figures B20-B29). It is impossible to produce concise and easily interpreted fits for conditional age-at-length data. As a proxy, for each year within fishery for which conditional age-at-length data were available the predicted age frequencies from the model were compared with the marginal age frequencies. While the model is not fitting to these data it is clear that the predicted age frequencies closely follow the marginal age frequencies (Figures B30-B34)

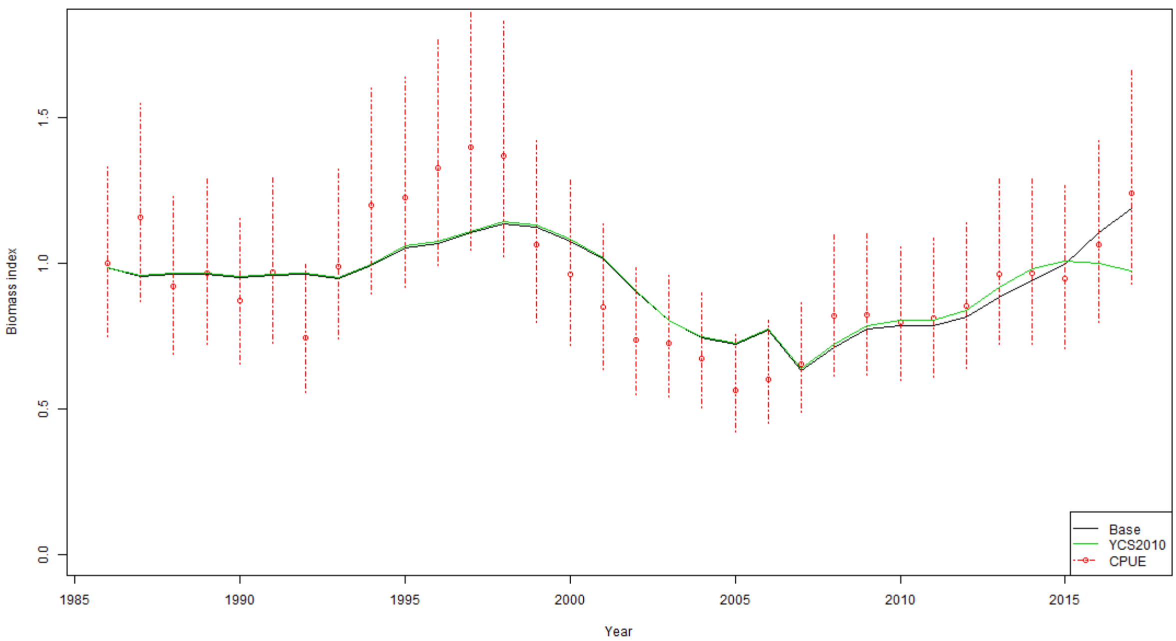

Figure B17: Western stock: base model MPD fit (black solid line) to the trawl fishery CPUE indices (red points with 95% CIs). The fit to the indices is also shown for a sensitivity where the 2011 and 2012 YCS are not estimated (YCS2010, green line).

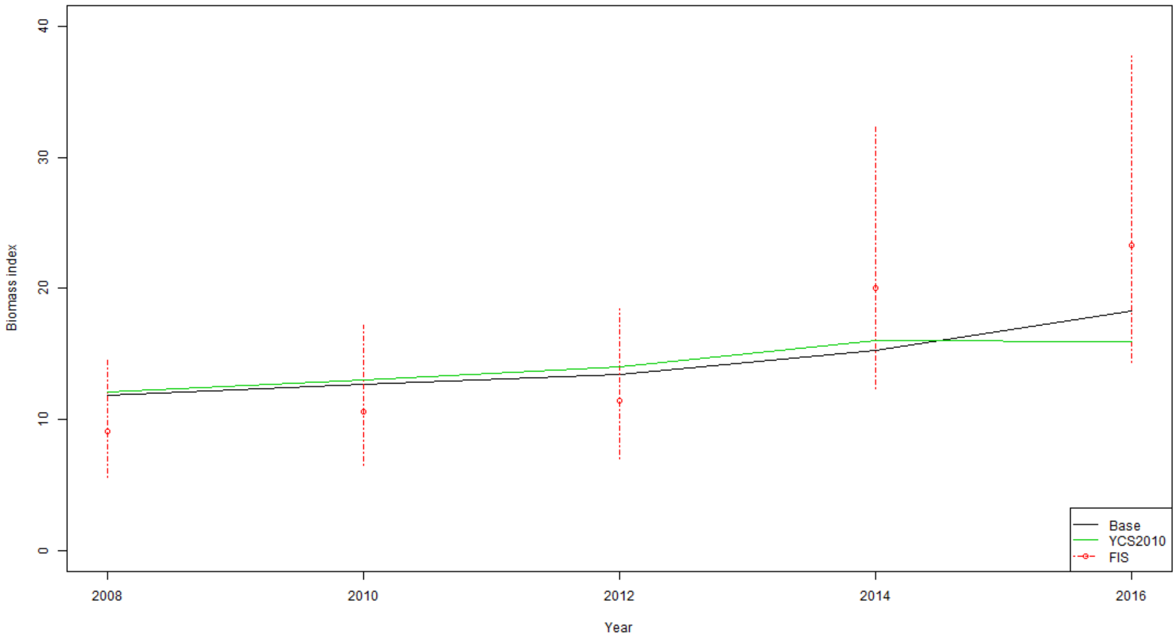

Figure B18: Western stock: base model MPD fit (black solid line) to the FIS indices (red points with 95% CIs). The fit to the indices is also shown for a sensitivity where the 2011 and 2012 YCS are not estimated (YCS2010, green line).

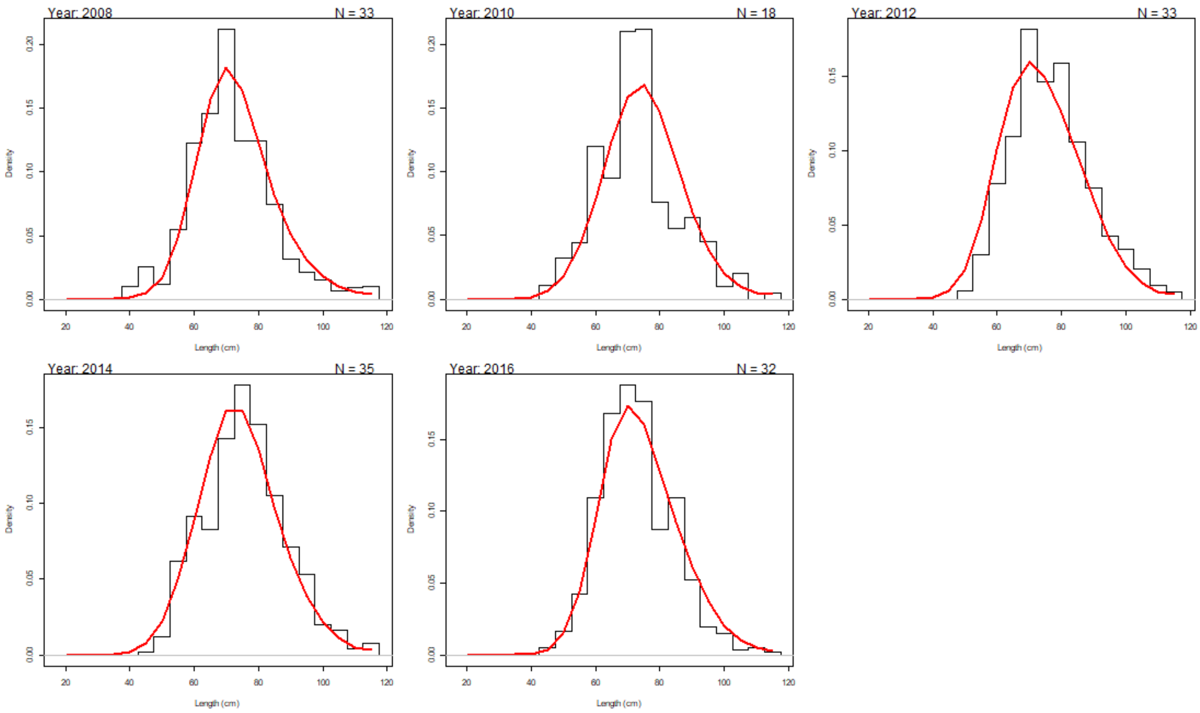

Figure B19: Western stock: base model MPD fit (red curves) to the FIS length frequencies (histograms). N is the effective sample size in the model.

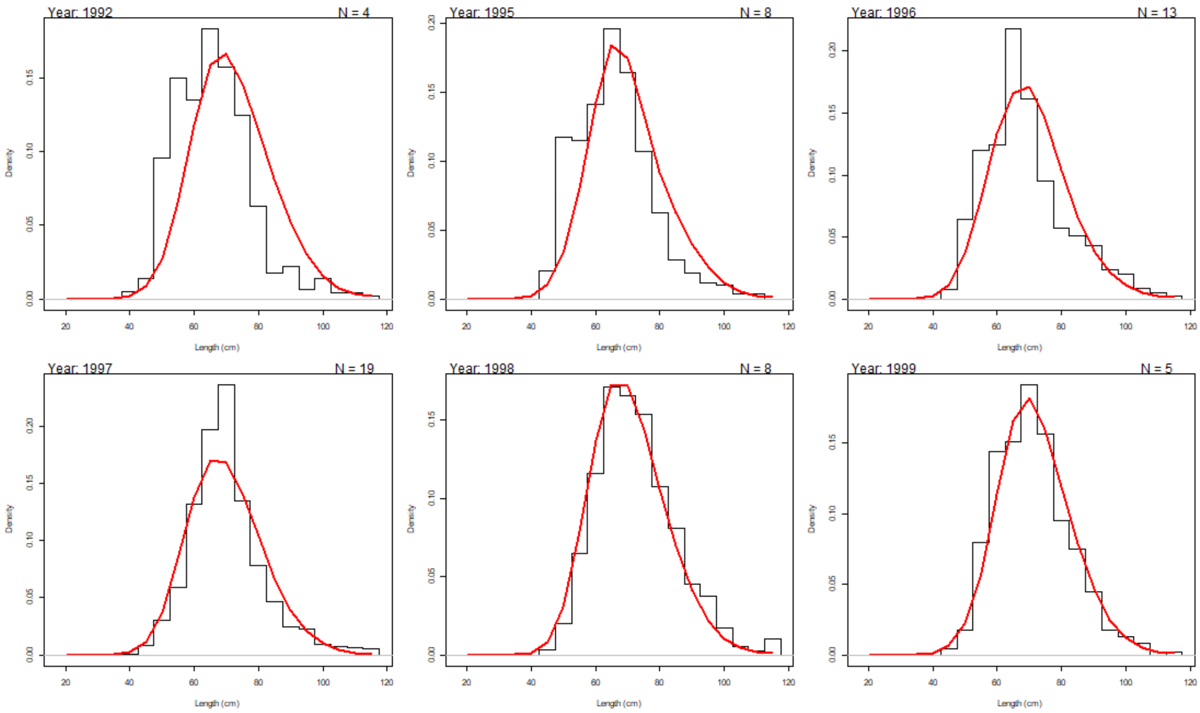

Figure B20: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at the port (prior to 2000). N is the effective sample size in the model.

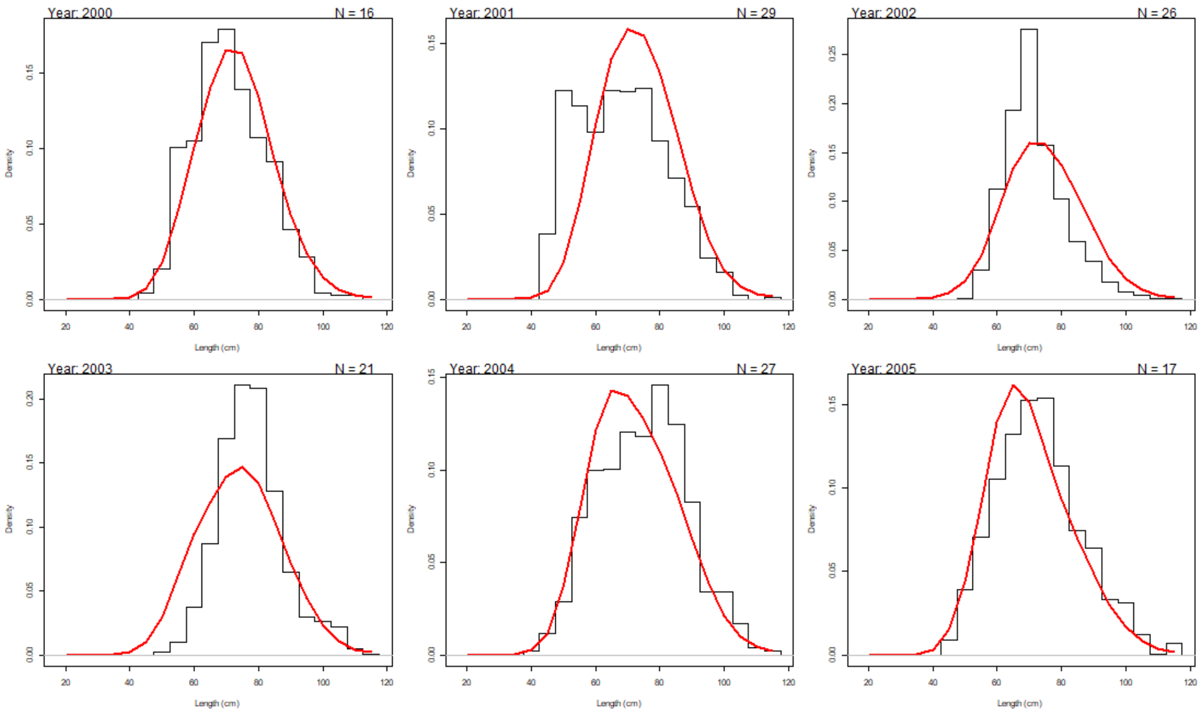

Figure B21: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at the port (2000-2005 inclusive). N is the effective sample size in the model.

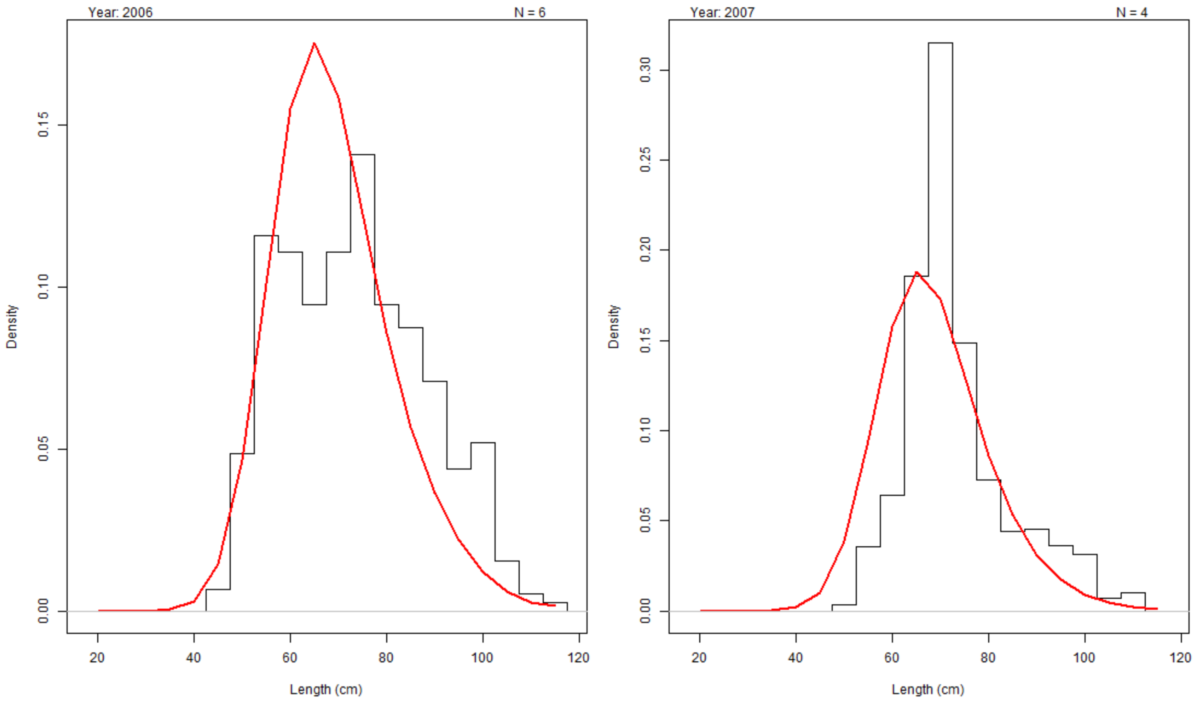

Figure B22: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at the port (2006 and 2007). N is the effective sample size in the model.

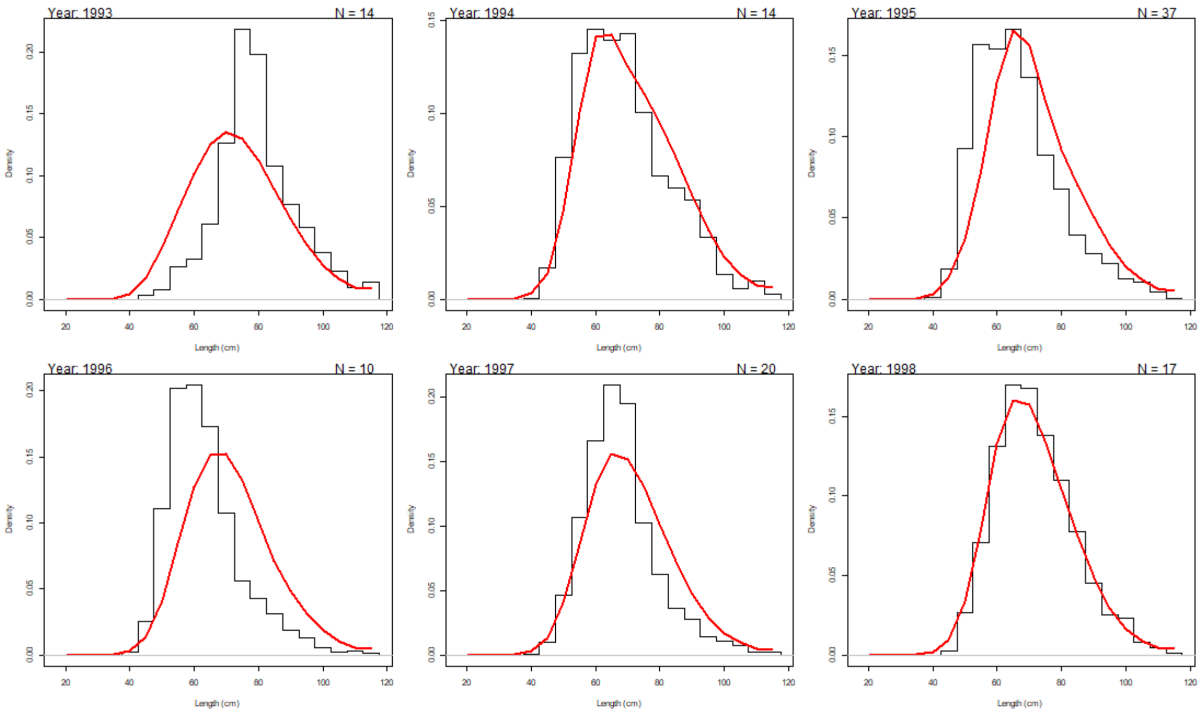

Figure B23: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at sea (prior to 1999). N is the effective sample size in the model.

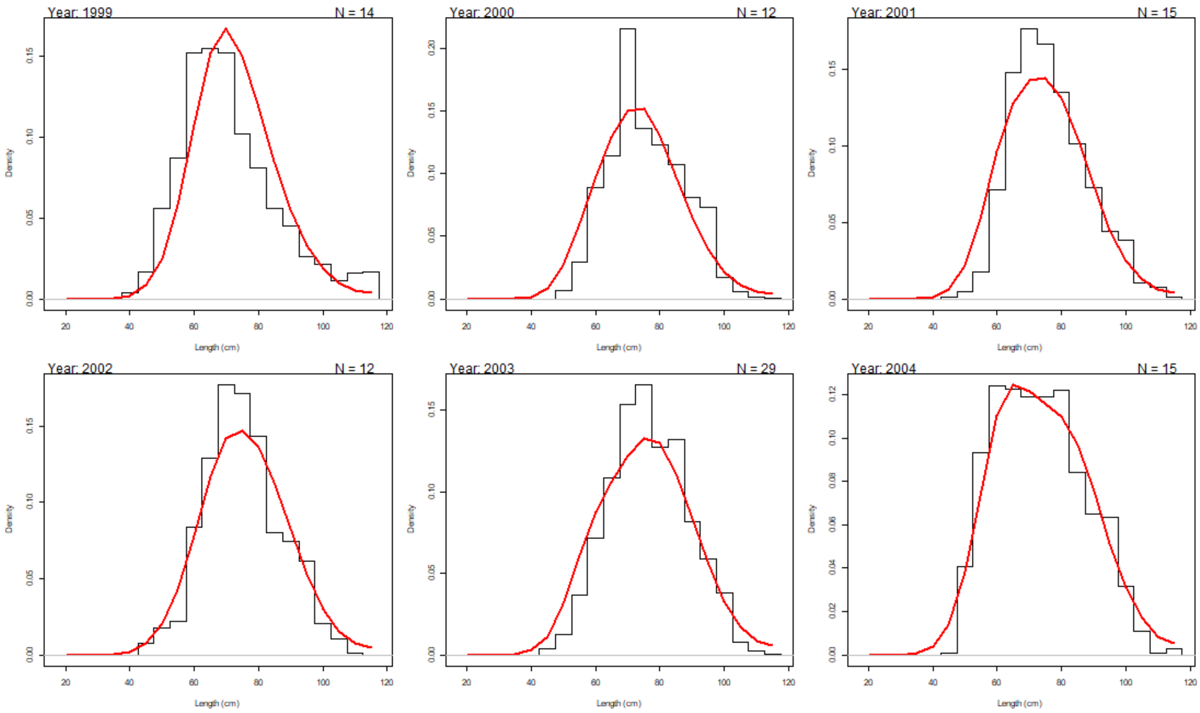

Figure B24: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at sea (1999-2004 inclusive). N is the effective sample size in the model.

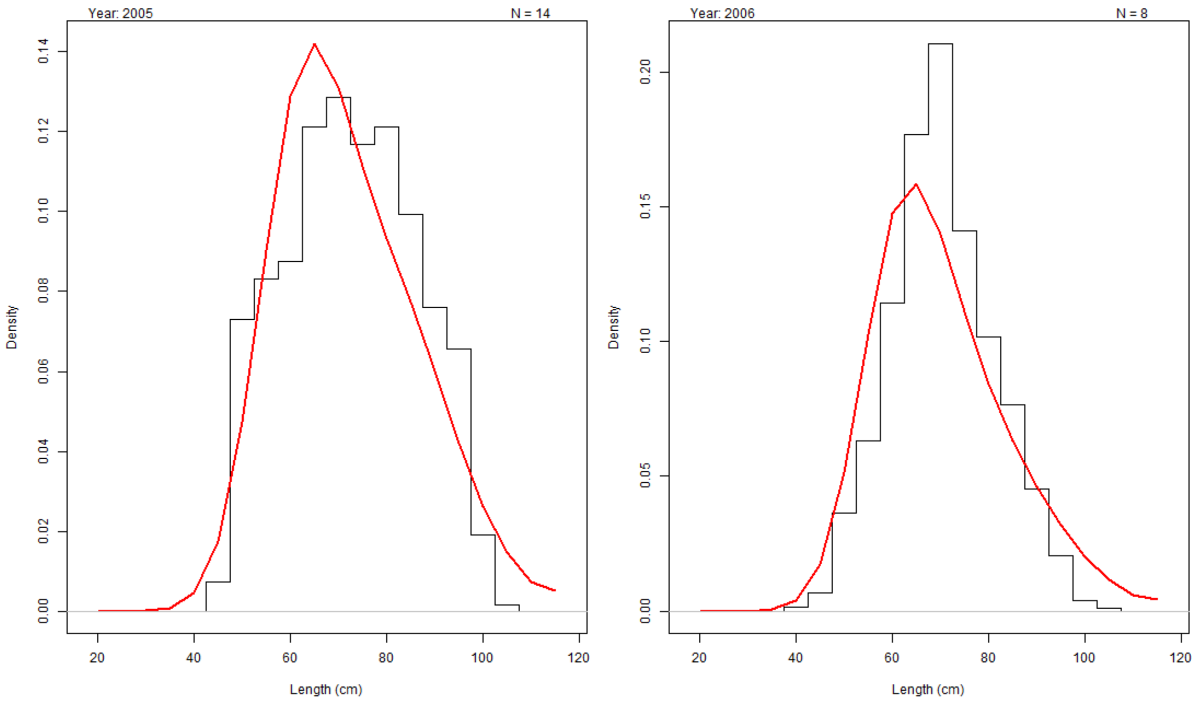

Figure B25: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at sea (2005 and 2006). N is the effective sample size in the model.

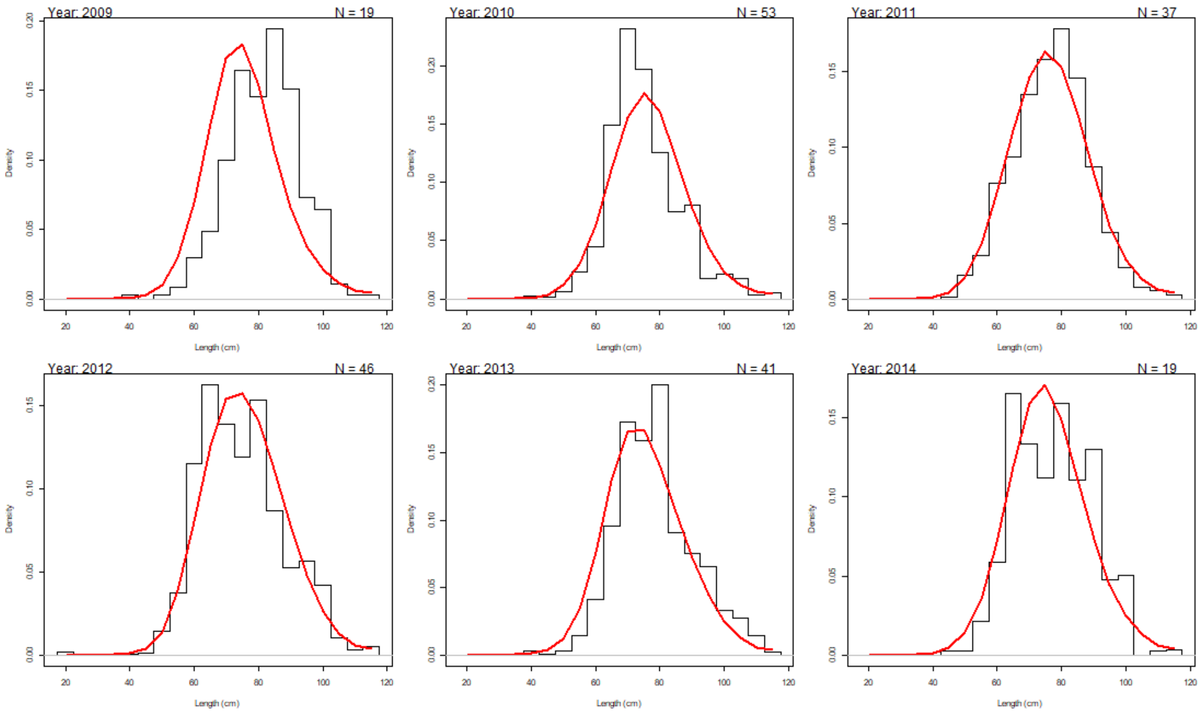

Figure B26: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at sea (2009-2014 inclusive). N is the effective sample size in the model.

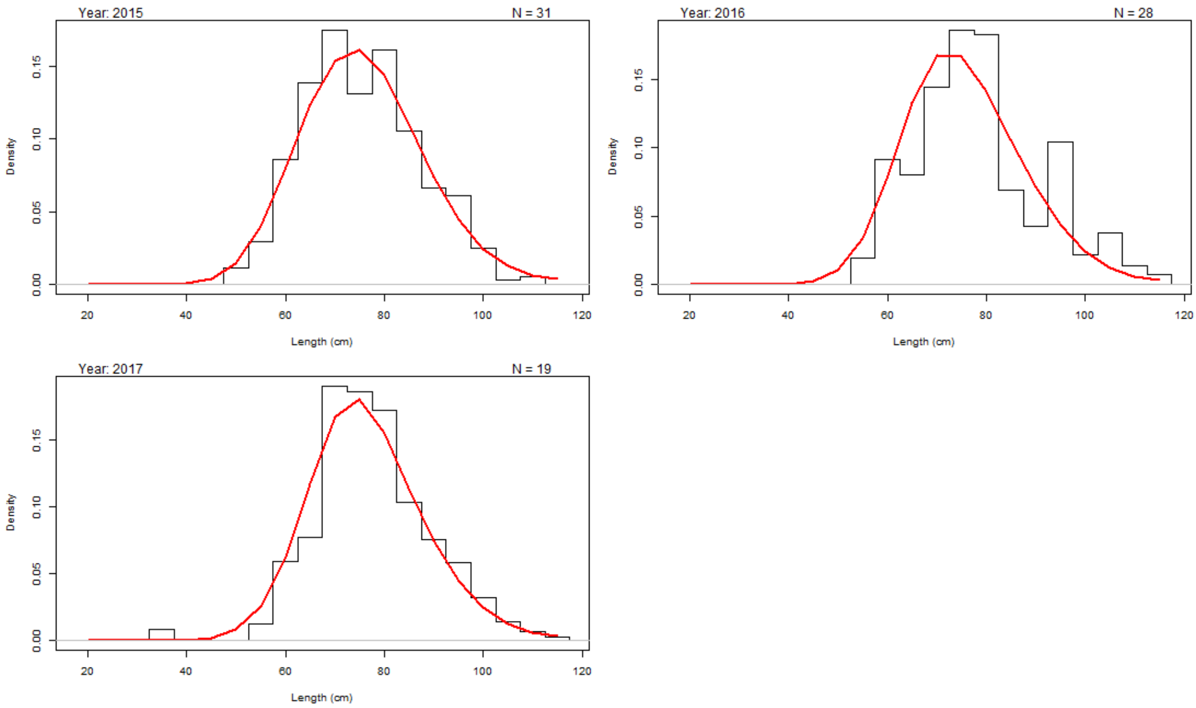

Figure B27: Western stock: base model MPD fit (red curves) to the trawl length frequencies (histograms) sampled at sea (2015-2017 inclusive). N is the effective sample size in the model.

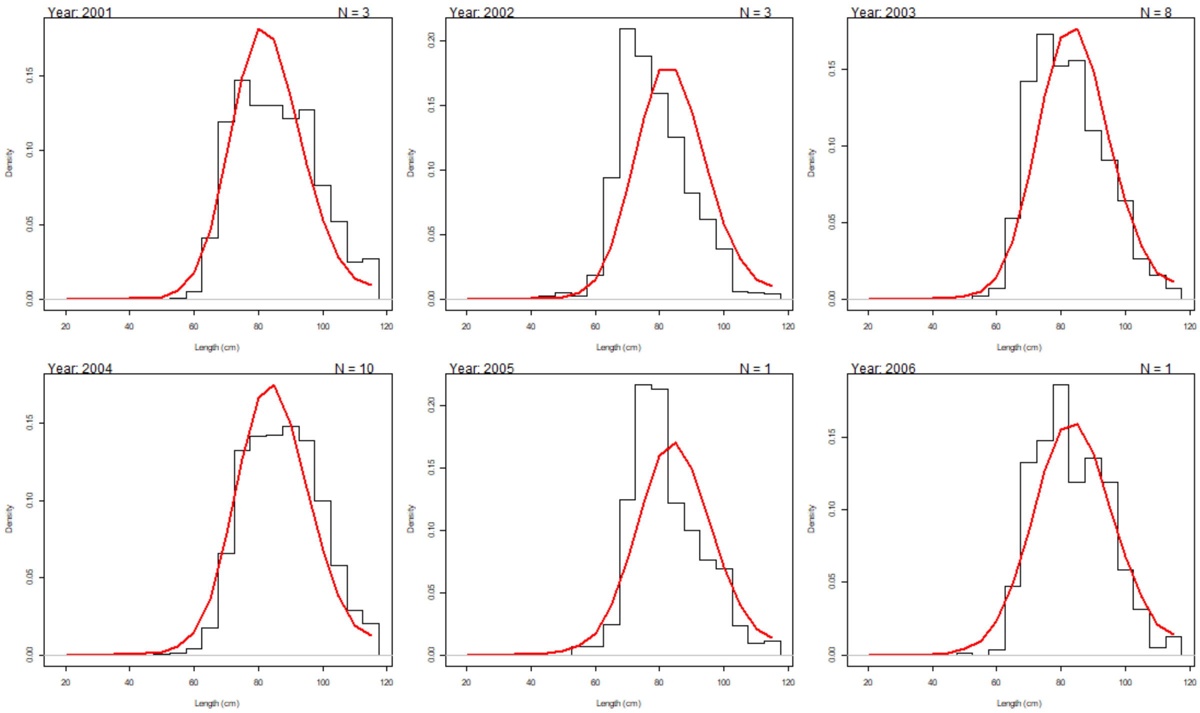

Figure B28: Western stock: base model MPD fit (red curves) to the non-trawl length frequencies (histograms) (2001-2006 inclusive). N is the effective sample size in the model.

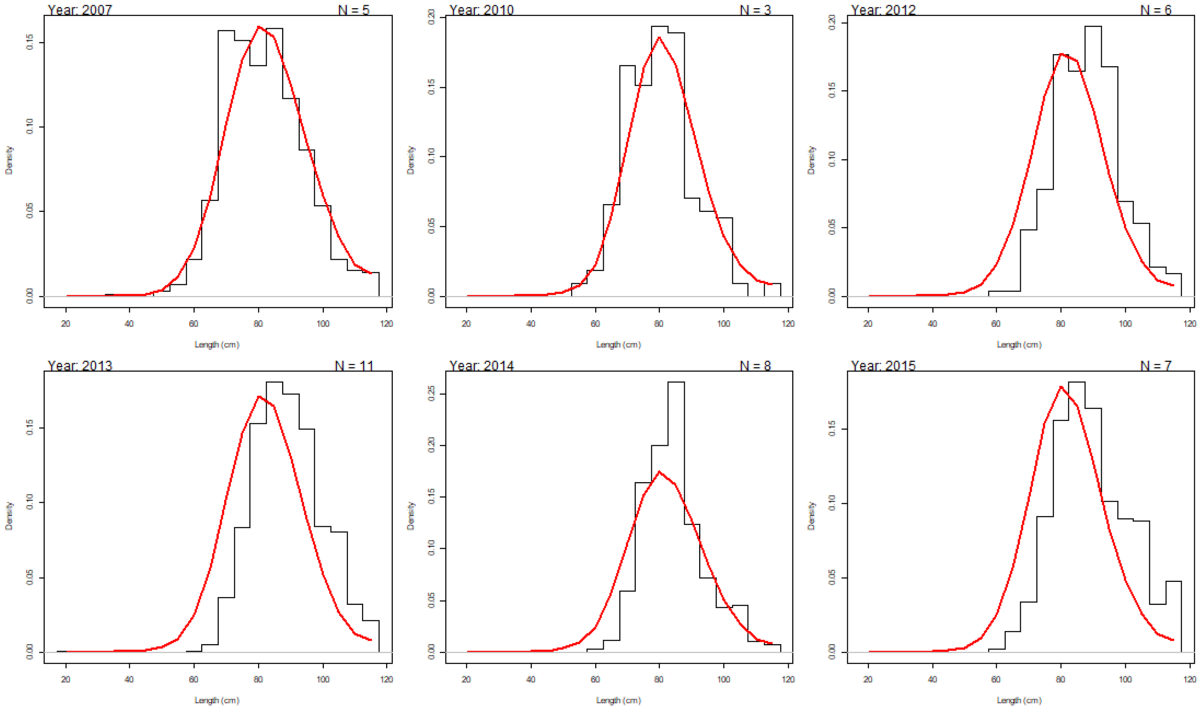

Figure B29: Western stock: base model MPD fit (red curves) to the non-trawl length frequencies (histograms) (after 2006). N is the effective sample size in the model.

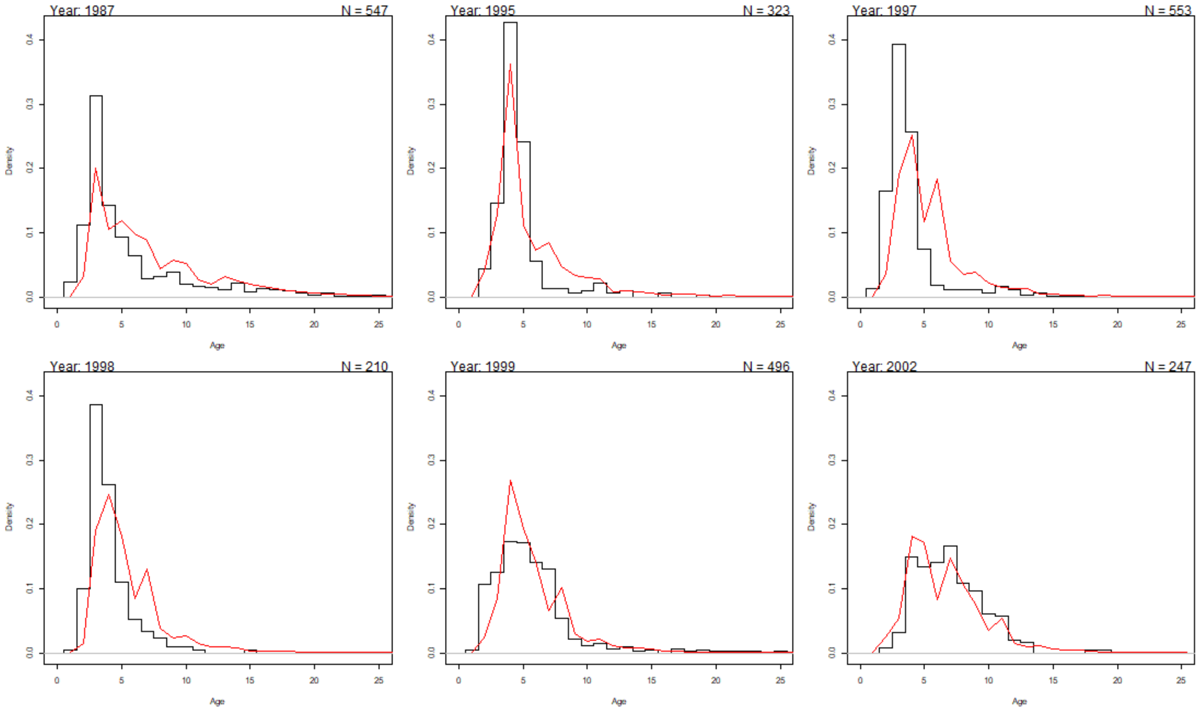

Figure B30: Western stock: base model MPD predicted age frequencies (red curves) compared to the trawl fishery age frequencies (histograms) for all aged fish in the western zone in the given year (years prior to 2003). N is the total number of aged fish in the given year (sexed and unsexed).

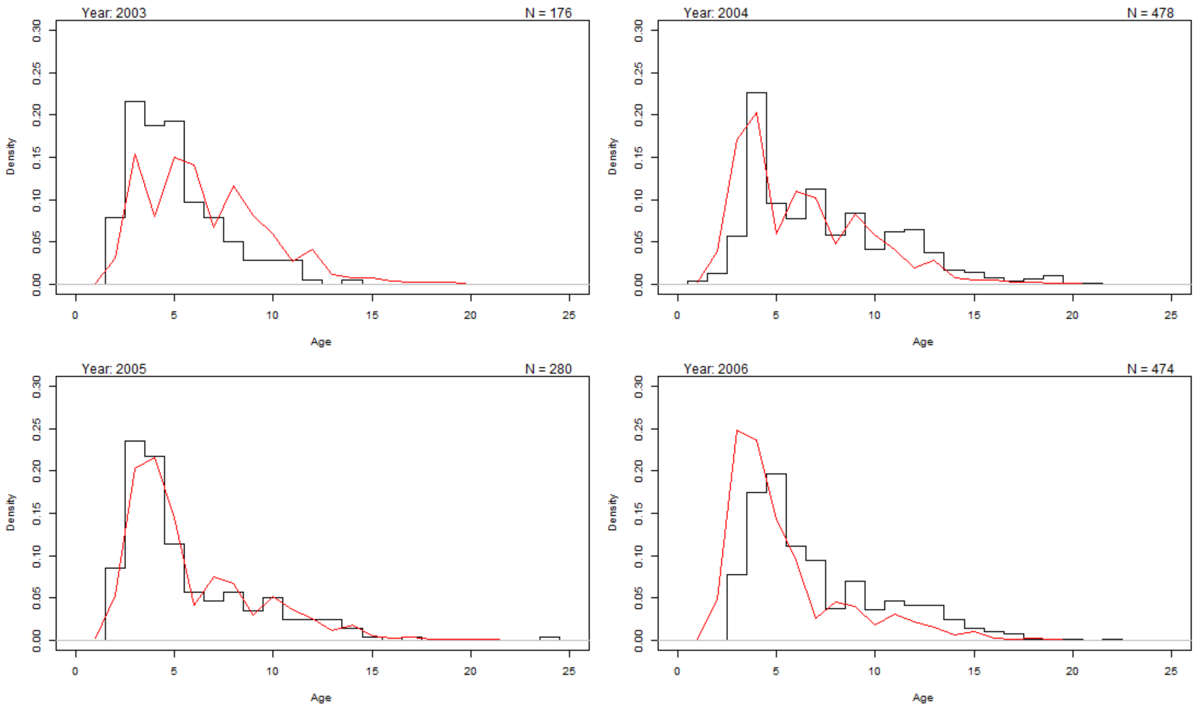

Figure B31: Western stock: base model MPD predicted age frequencies (red curves) compared to the trawl fishery age frequencies (histograms) for all aged fish in the western zone in the given year (2003-2006 inclusive). N is the total number of aged fish in the given year (sexed and unsexed).

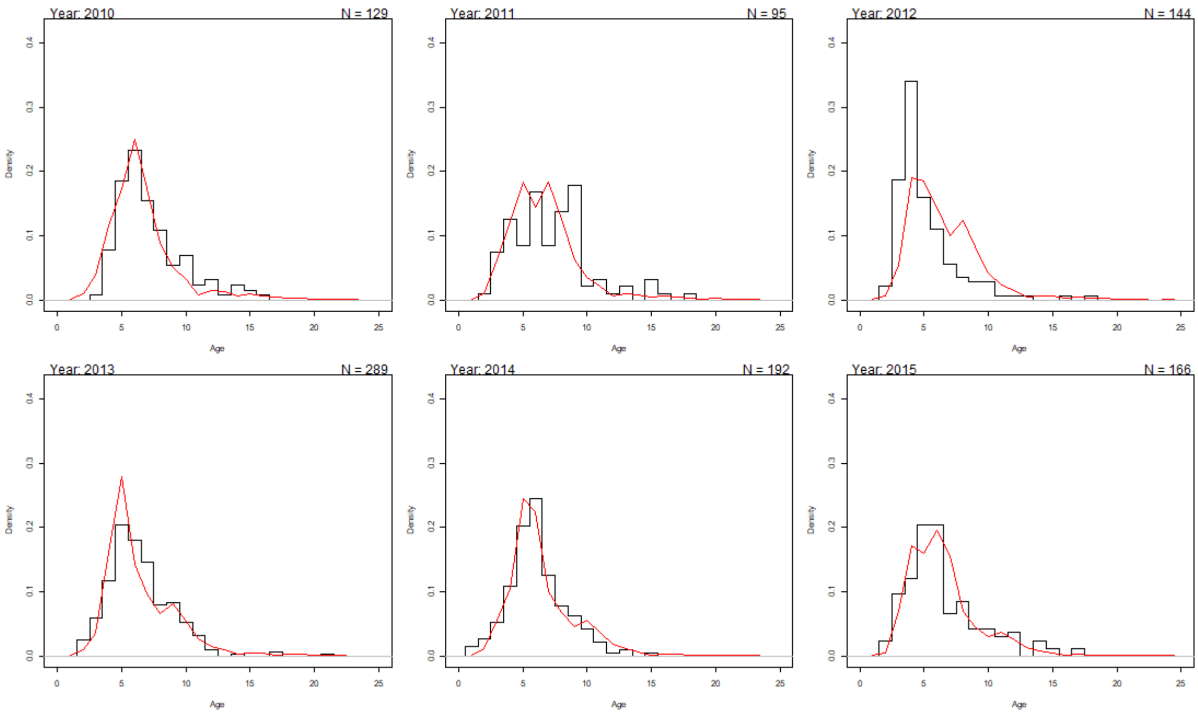

Figure B32: Western stock: base model MPD predicted age frequencies (red curves) compared to the trawl fishery age frequencies (histograms) for all aged fish in the western zone in the given year (2010-2015 inclusive). N is the total number of aged fish in the given year (sexed and unsexed).

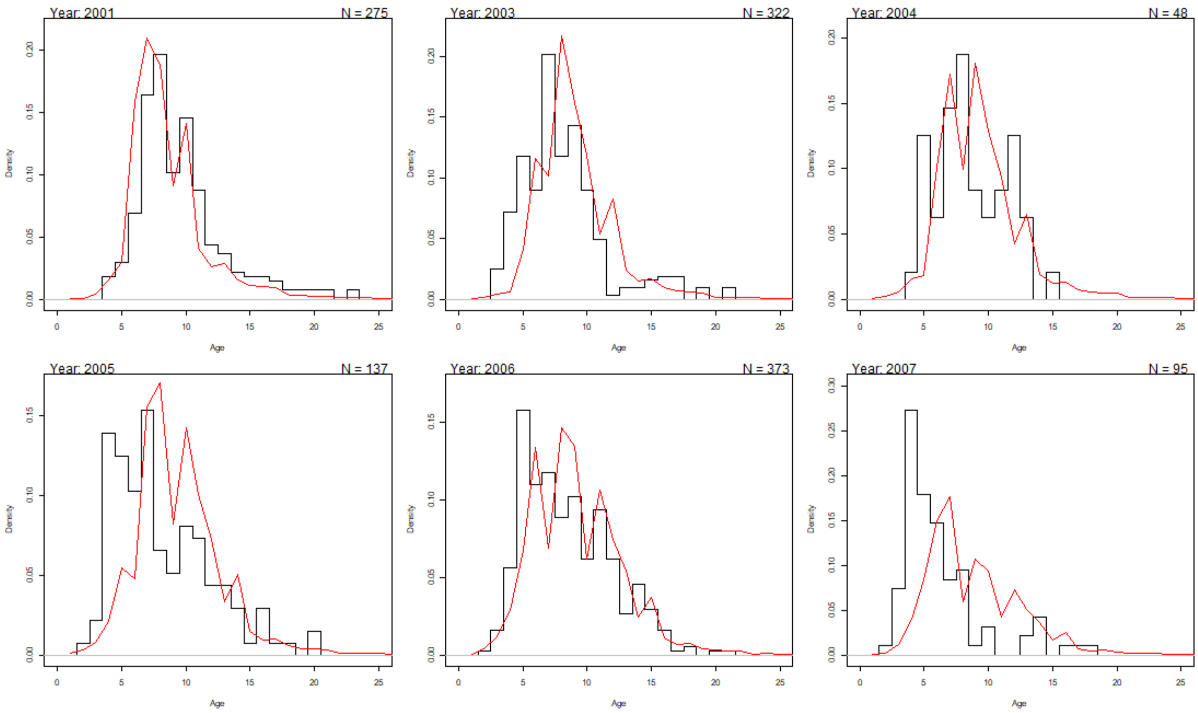

Figure B33: Western stock: base model MPD predicted age frequencies (red curves) compared to the non-trawl fishery age frequencies (histograms) for all aged fish in the western zone in the given year (before 2008). N is the total number of aged fish in the given year (sexed and unsexed).

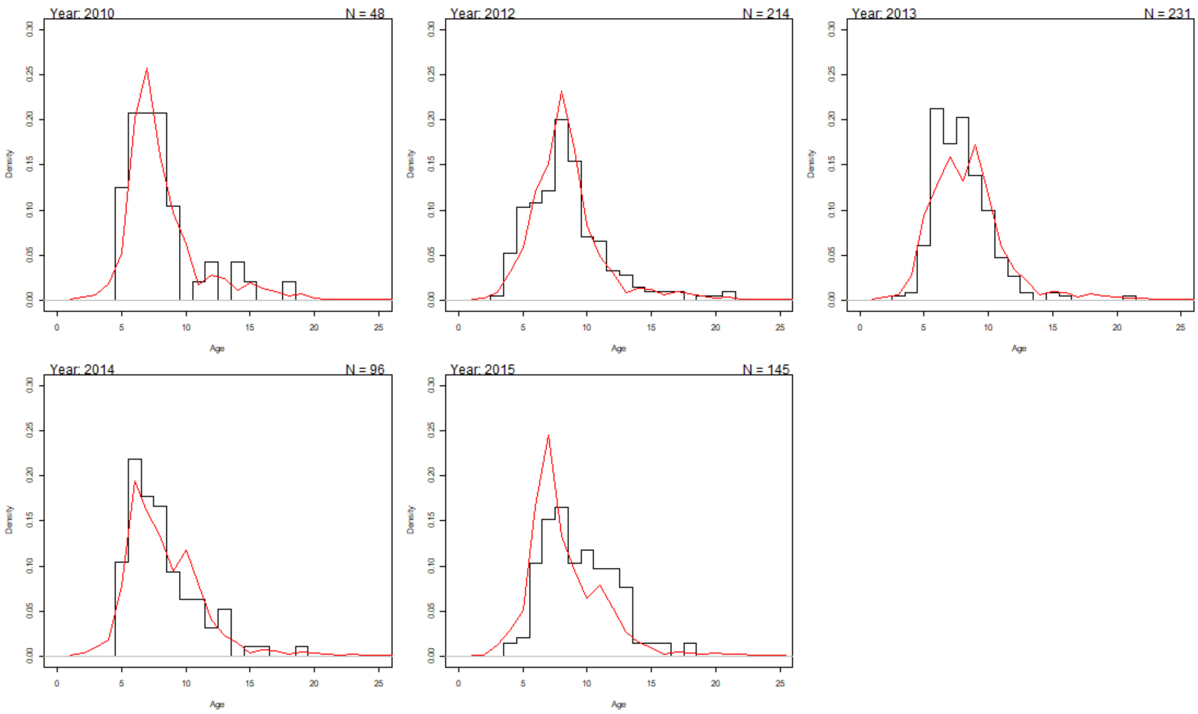

Figure B34: Western stock: base model MPD predicted age frequencies (red curves) compared to the non-trawl fishery age frequencies (histograms) for all aged fish in the western zone in the given year (after 2009). N is the total number of aged fish in the given year (sexed and unsexed).

Appendix C: MCMC chain diagnostics

Eastern models

Reference model

For the eastern reference model ten chains were run. One in every one thousand samples were retained and each chain had approximately 2000 retained samples. The first 400 retained samples were discarded as a burn-in based on the distribution of the objective function values over all chains (Figure C1). Estimates use all chains combined after the burn-in (approximately 16000 samples) except for projection based estimates which used a random subsample of 3000.

The diagnostics for this run were acceptable. The histograms for B_0, M, and current stock status comparing the first half of all chains combined (after burn-in) and the second half of all chains combined (after burn-in) showed very similar results (Figures C2-C4). The plot of standardised medians for all of the estimated parameters for the first half of all chains combined and the second half of all chains combined showed no problem parameters with the largest deviations between the two halves being no more than 15% (Figure C5). For the spawning stock biomass (SSB) trajectory the deviation between the two halves was less than 5% for every year (Figure C6).

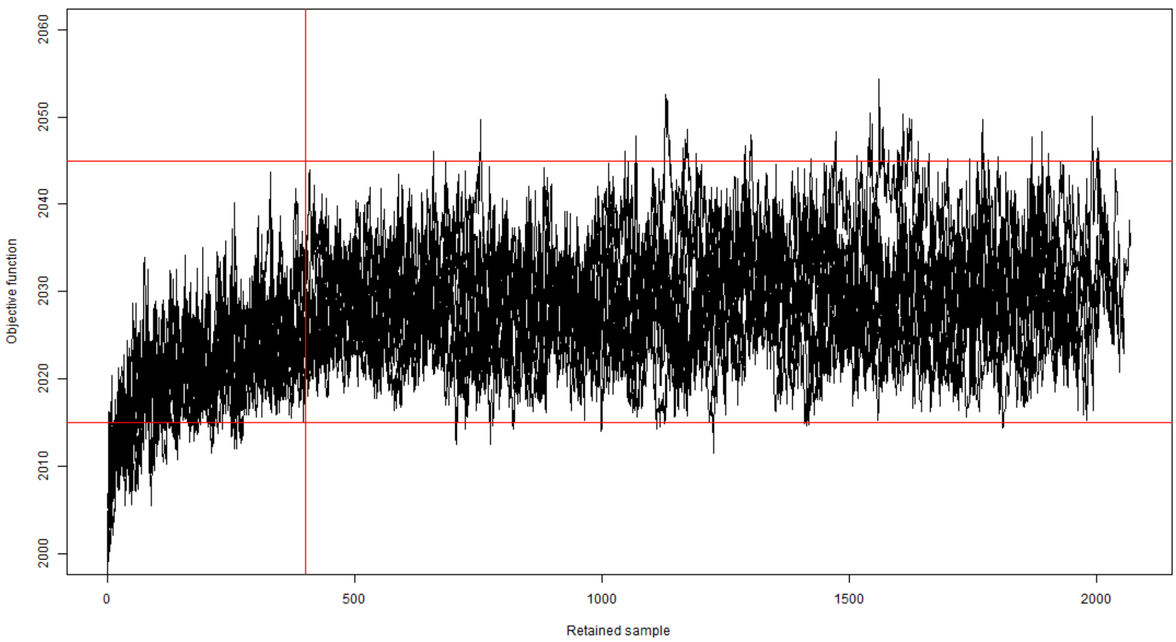

Figure C1: Eastern stock, reference: objective function value for each retained sample for each chain. Horizontal lines are marked at 2015 and 2045 to aid the eye. The vertical line is at 400 which is the burn-in that was used.

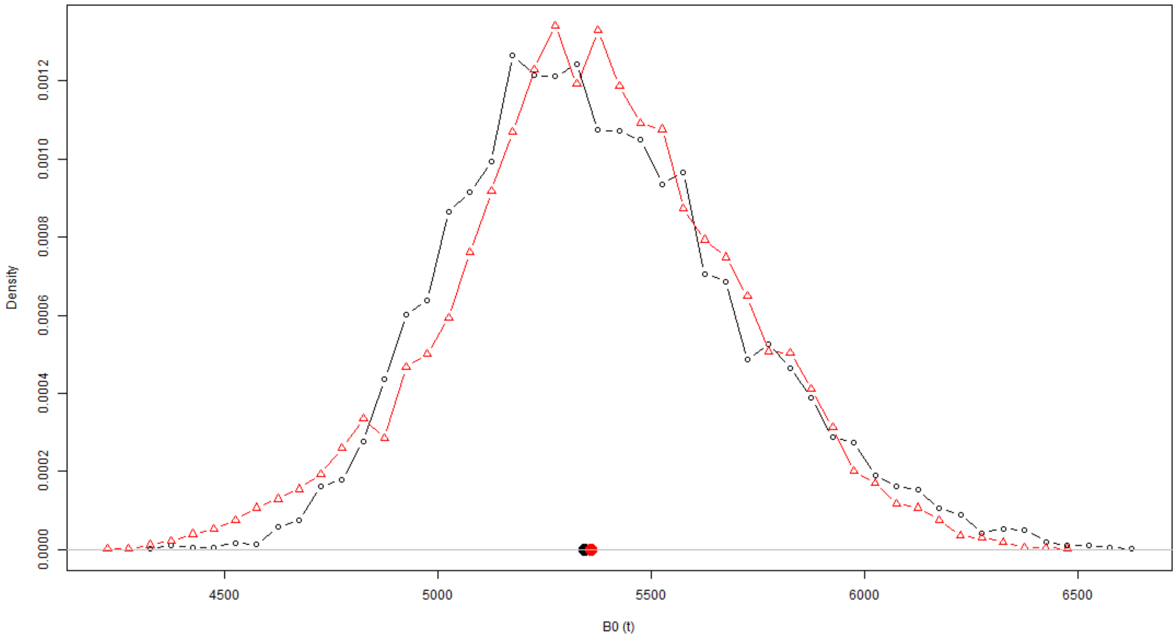

Figure C2: Eastern stock, reference: histograms of B_0 for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (both at approximately B_0 = 5350 t).

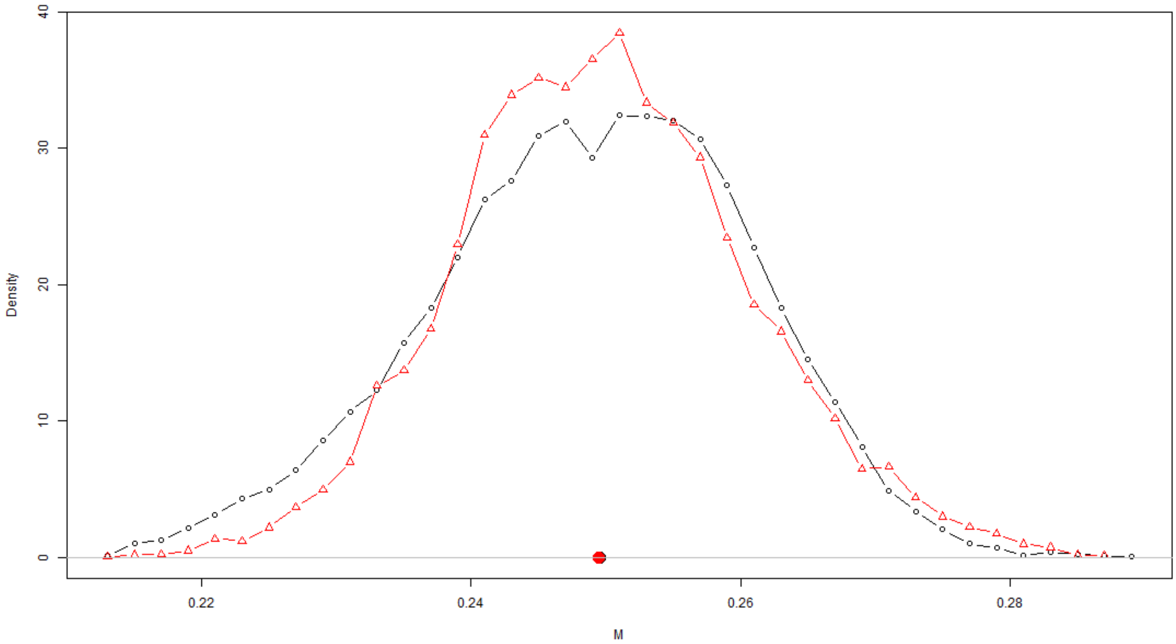

Figure C3: Eastern stock, reference: histograms of M for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (both at approximately M = 0.25).

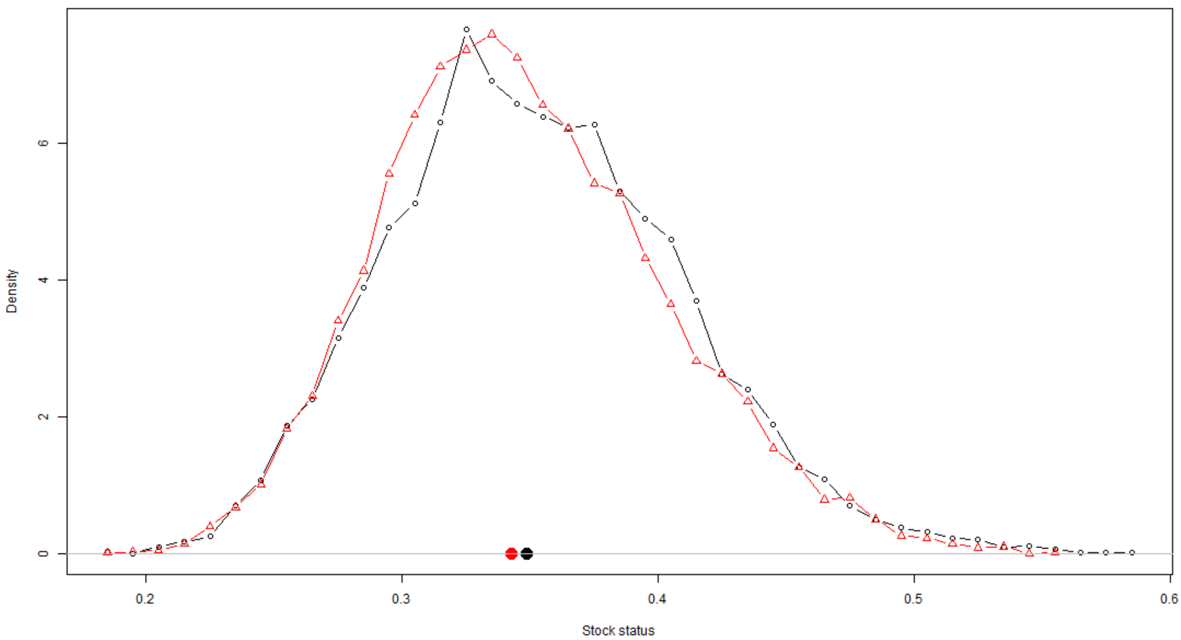

Figure C4: Eastern stock, reference: histograms of 2018 stock status (B_{2018}/B_0) for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (at approximately 0.35 and 0.34).

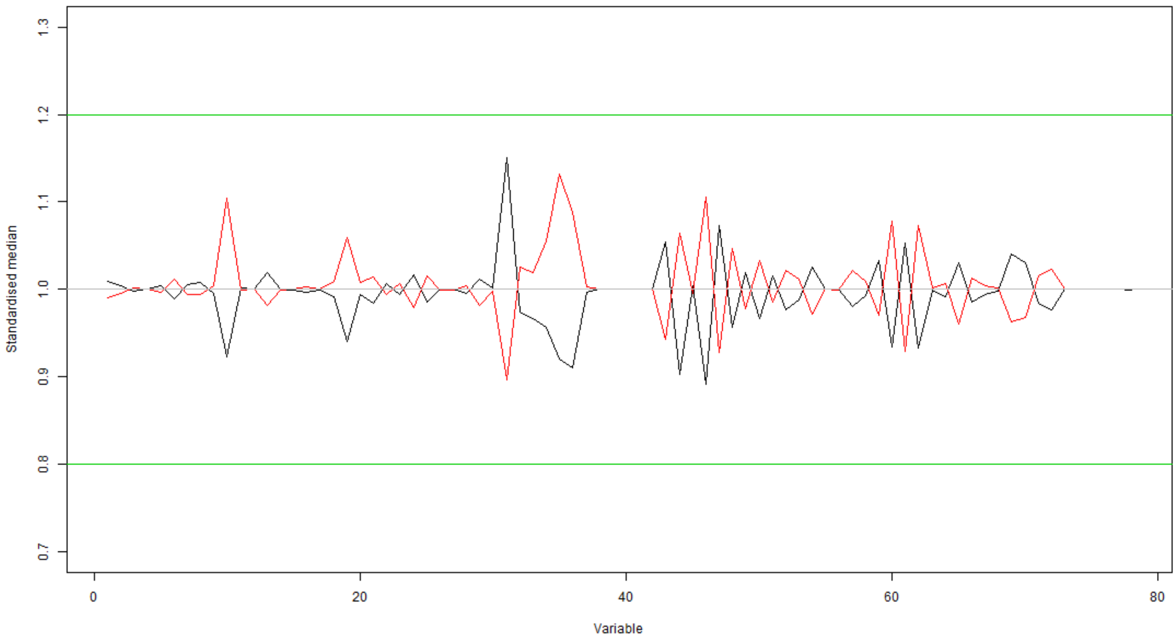

Figure C5: Eastern stock, reference: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for each free parameter estimated. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

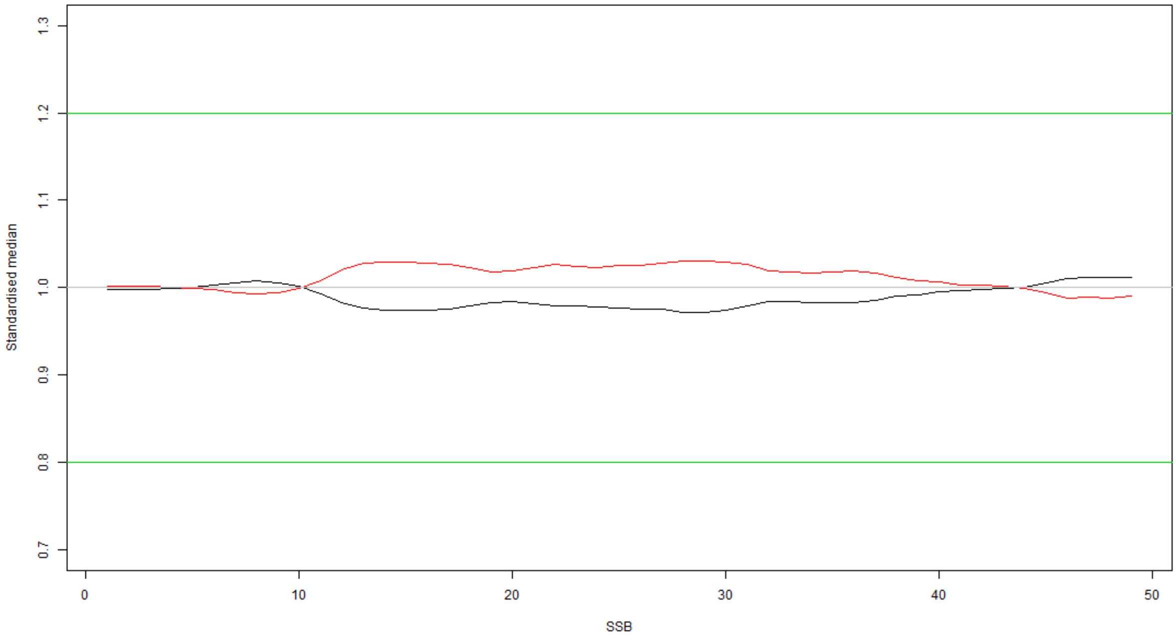

Figure C6: Eastern stock, reference: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for SSB from 1970 to 2018 inclusive. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

M=0.23

For the eastern model with M=0.23 six chains were run. One in every one thousand samples were retained and each chain had approximately 1900 retained samples. The first 250 retained samples were discarded as a burn-in based on the distribution of the objective function values over all chains (Figure C7). Estimates use all chains combined after the burn-in (approximately 10000 samples) except for projection based estimates which used a random subsample of 3000.

The diagnostics for this run were acceptable. The histograms for B_0 and current stock status comparing the first half of all chains combined (after burn-in) and the second half of all chains combined (after burn-in) showed very similar results (Figures C8-C9). The plot of standardised medians for all of the estimated parameters for the first half of all chains combined and the second half of all chains combined showed no problem parameters with the largest deviations between the two halves being no more than 15% (Figure C10). For the spawning stock biomass (SSB) trajectory the deviation between the two halves was less than 3% for every year (Figure C11).

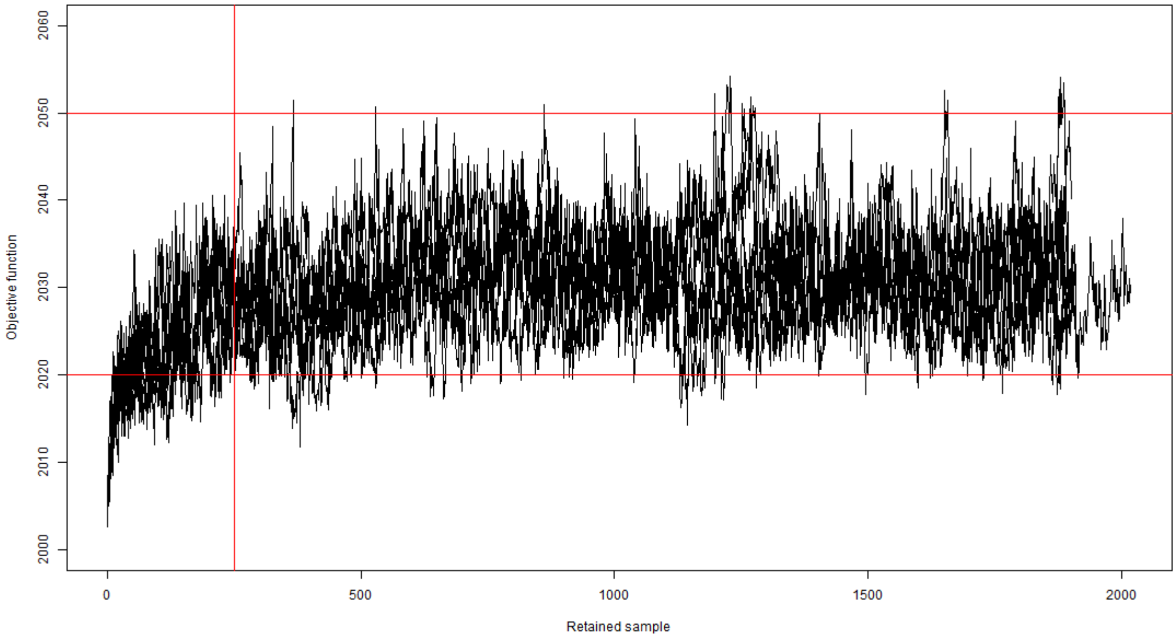

Figure C7: Eastern stock, M=0.23: Objective function value for each retained sample for each chain. Horizontal lines are marked at 2020 and 2050 to aid the eye. The vertical line is at 250 which is the burn-in that was used.

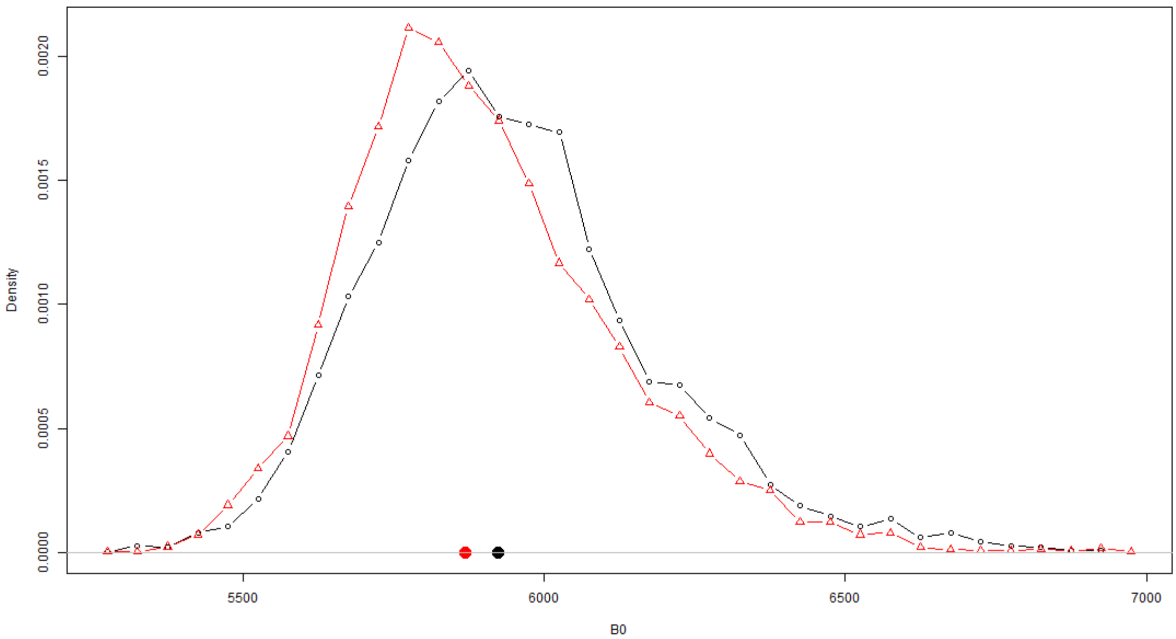

Figure C8: Eastern stock, M=0.23: histograms of B_0 for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (both at approximately B_0 = 5900 t).

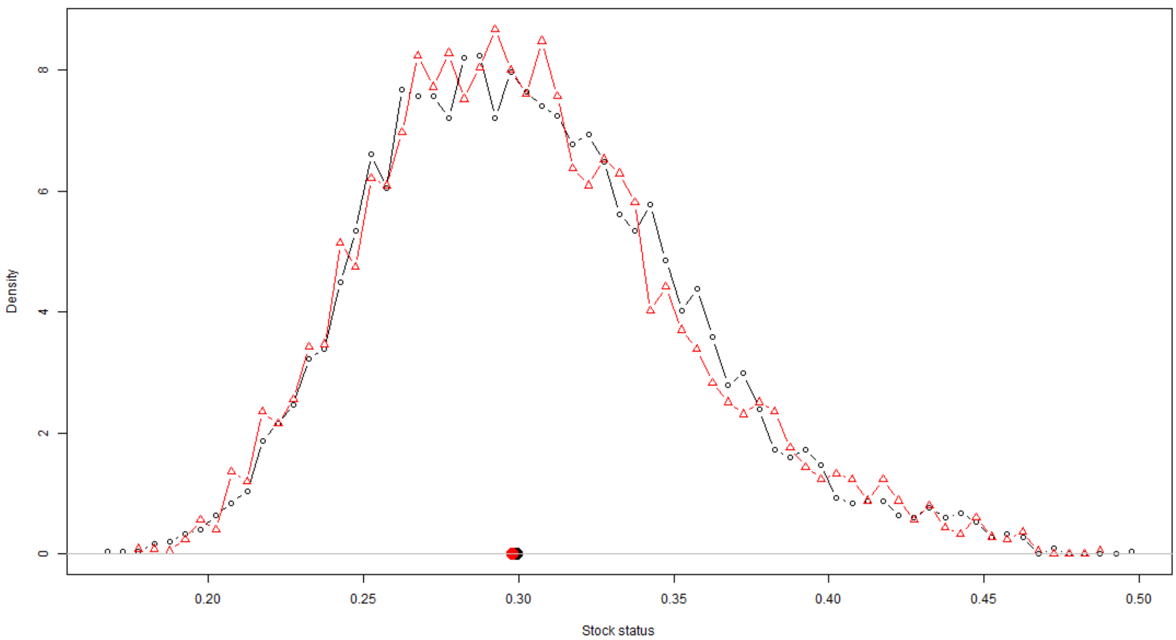

Figure C9: Eastern stock, M=0.23: Histograms of 2018 stock status (B_{2018}/B_0) for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (both at approximately 0.30).

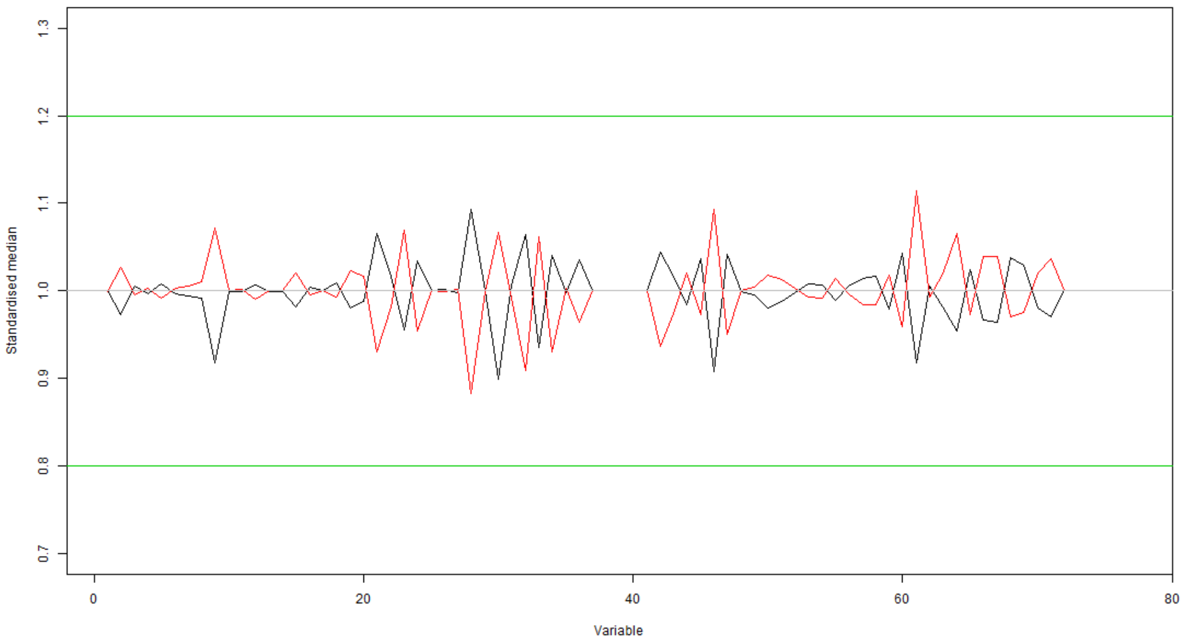

Figure C10: Eastern stock, M=0.23: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for each free parameter estimated. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

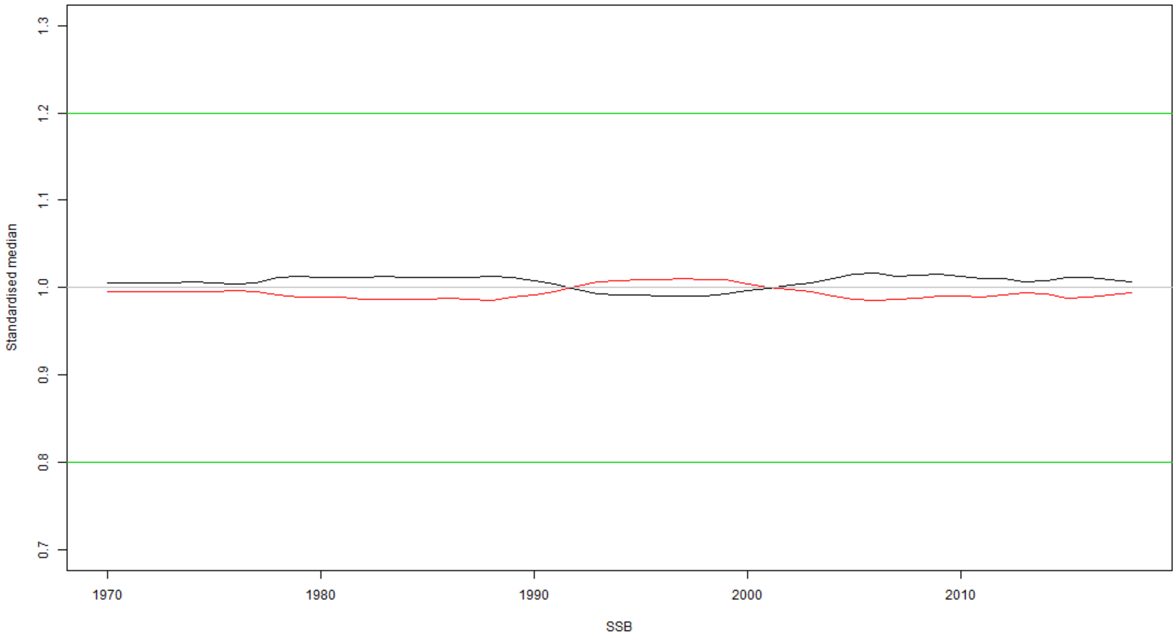

Figure C11: Eastern stock, M=0.23: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for SSB from 1970 to 2018 inclusive. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

Period CPUE with M=0.23

For the eastern model using the period CPUE with M=0.23 six chains were run. One in every one thousand samples were retained and each chain had approximately 1800 retained samples. The first 250 retained samples were discarded as a burn-in based on the distribution of the objective function values over all chains (Figure C12). Estimates use all chains combined after the burn-in (approximately 9400 samples) except for projection based estimates which used a random subsample of 3000.

The diagnostics for this run were acceptable. The histograms for B_0 and current stock status comparing the first half of all chains combined (after burn-in) and the second half of all chains combined (after burn-in) showed very similar results (Figures C13-C14). The plot of standardised medians for all of the estimated parameters for the first half of all chains combined and the second half of all chains combined showed no problem parameters with the largest deviations between the two halves being no more than 10% (Figure C15). For the spawning stock biomass (SSB) trajectory the deviation between the two halves was less than 5% for every year (Figure C16).

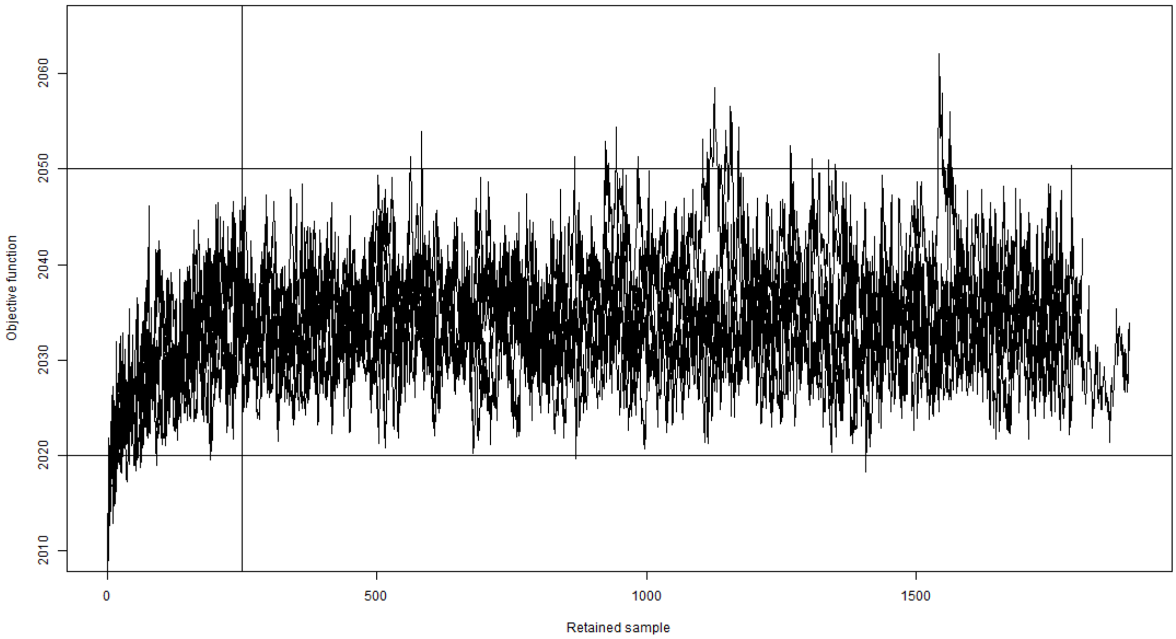

Figure C12: Eastern stock, period CPUE with M=0.23: objective function value for each retained sample for each chain. Horizontal lines are marked at 2020 and 2050 to aid the eye. The vertical line is at 250 which is the burn-in that was used.

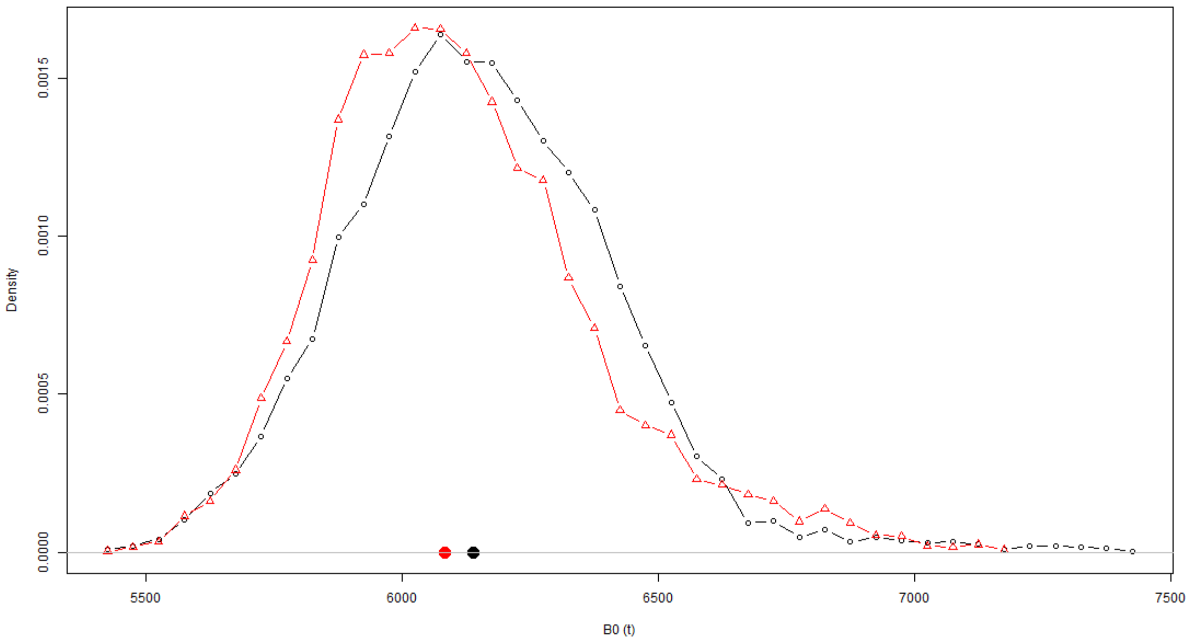

Figure C13: Eastern stock, period CPUE with M=0.23: histograms of B_0 for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (at approximately B_0 = 6140 t, 6080 t).

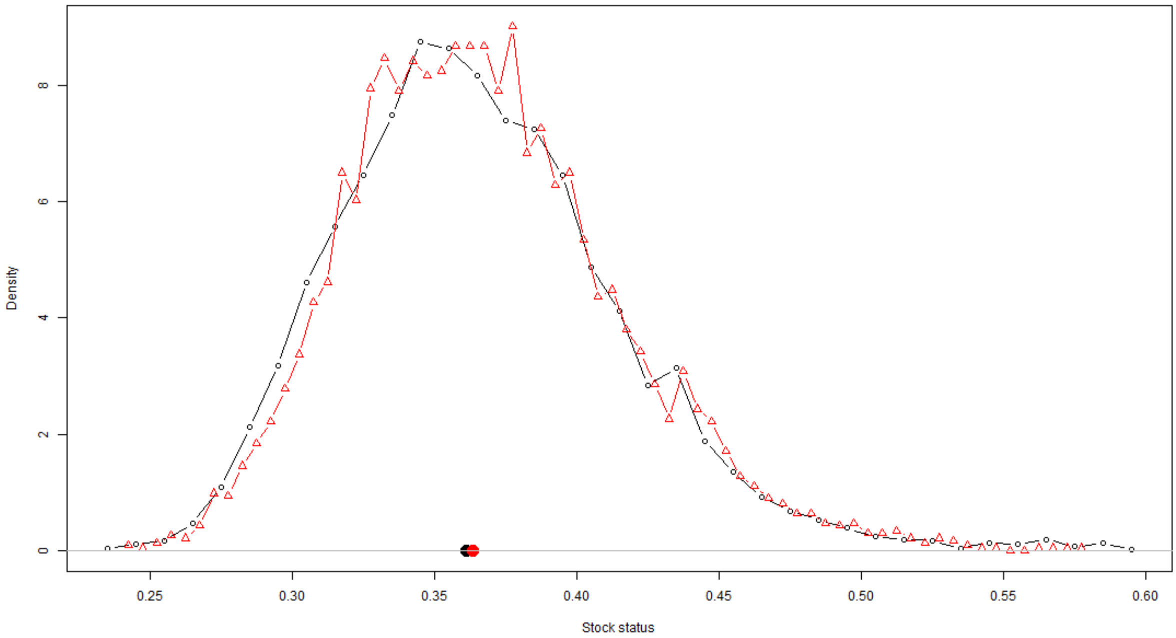

Figure C14: Eastern stock, period CPUE with M=0.23: histograms of 2018 stock status (B_{2018}/B_0) for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (both at approximately 0.36).

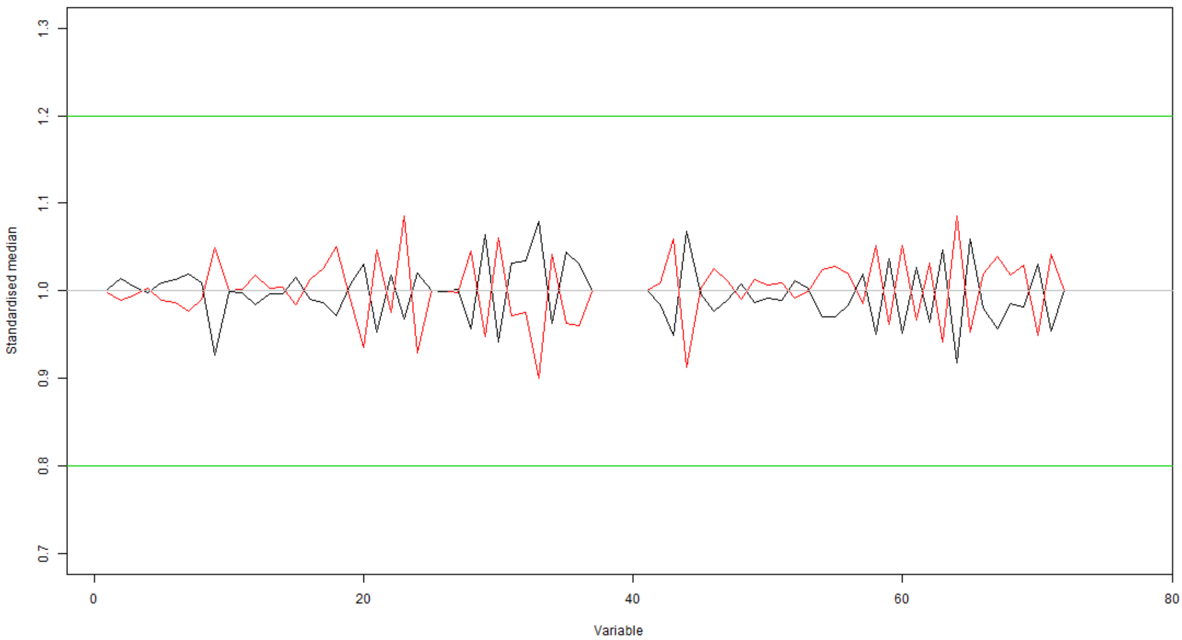

Figure C15: Eastern stock, period CPUE with M=0.23: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for each free parameter estimated. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

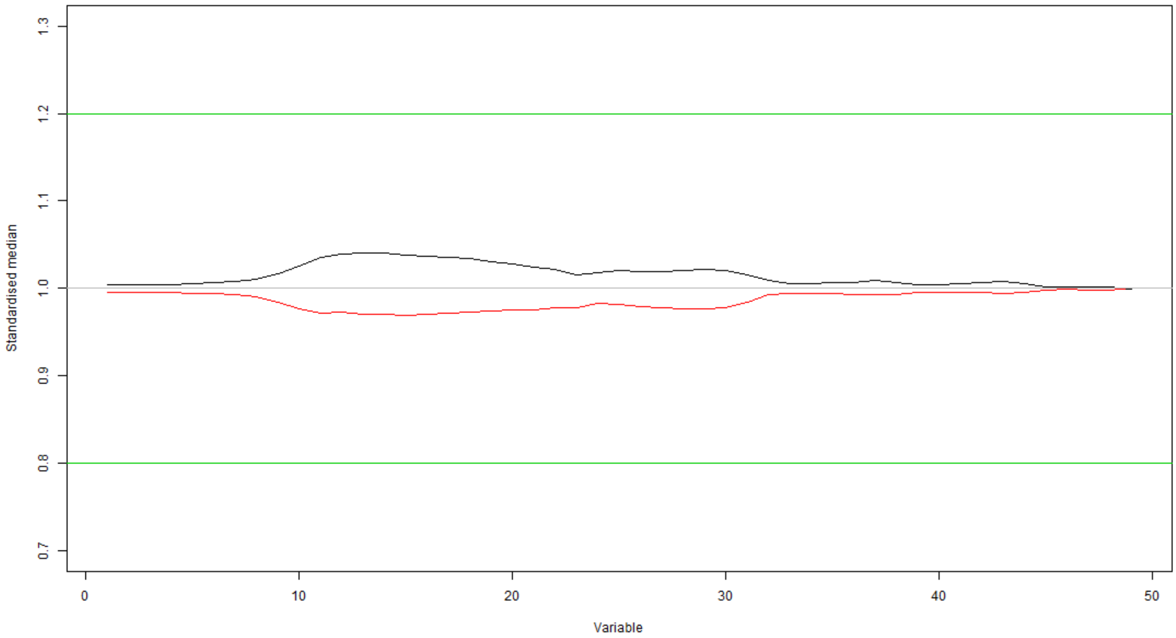

Figure C16: Eastern stock, period CPUE with M=0.23: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for SSB from 1970 to 2018 inclusive. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

Western models

Base model

For the western base model ten chains were run. One in every one thousand samples were retained and each chain had approximately 1750 retained samples. The first 250 retained samples were discarded as a burn-in based on the distribution of the objective function values over all chains (Figure C17). Estimates use all chains combined after the burn-in (approximately 15000 samples) except for projection based estimates which used a random subsample of 3000.

The diagnostics for this run were acceptable. The histograms for B_0, M, and current stock status comparing the first half of all chains combined (after burn-in) and the second half of all chains combined (after burn-in) showed very similar results (Figures C18-C20). The plot of standardised medians for all of the estimated parameters for the first half of all chains combined and the second half of all chains combined showed no problem parameters with the largest deviations between the two halves being no more than 15% (Figure C21). For the spawning stock biomass (SSB) trajectory the deviation between the two halves was less than 5% for every year (Figure C22).

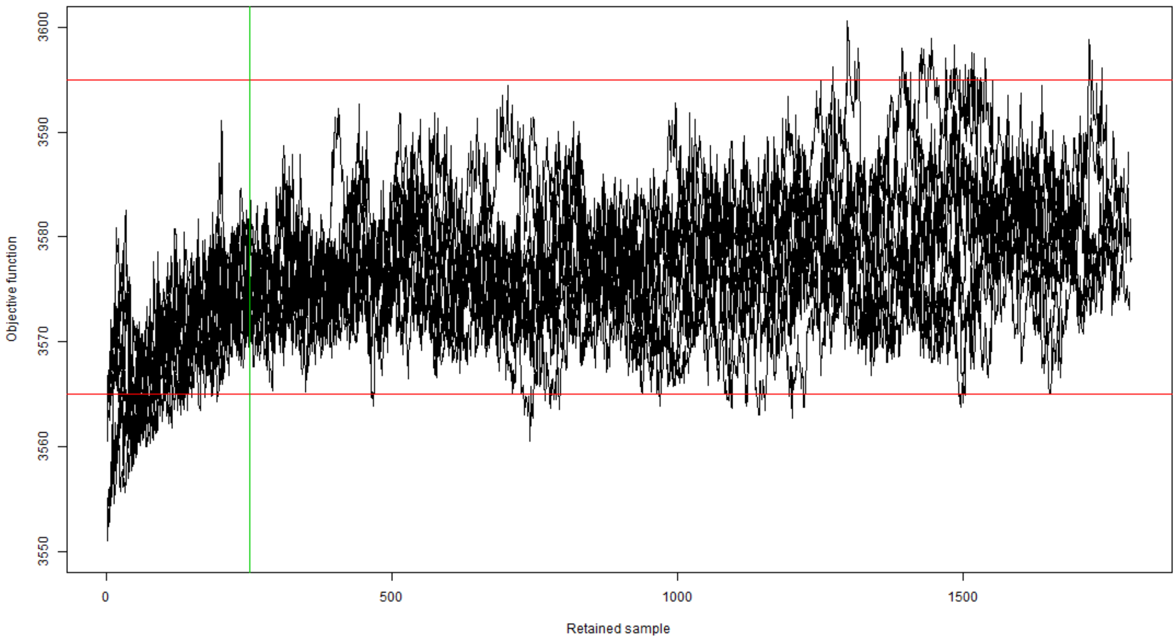

Figure C17: Western stock, base: objective function value for each retained sample for each chain. Horizontal lines are marked at 3565 and 3595 to aid the eye. The vertical line is at 250 which is the burn-in that was used.

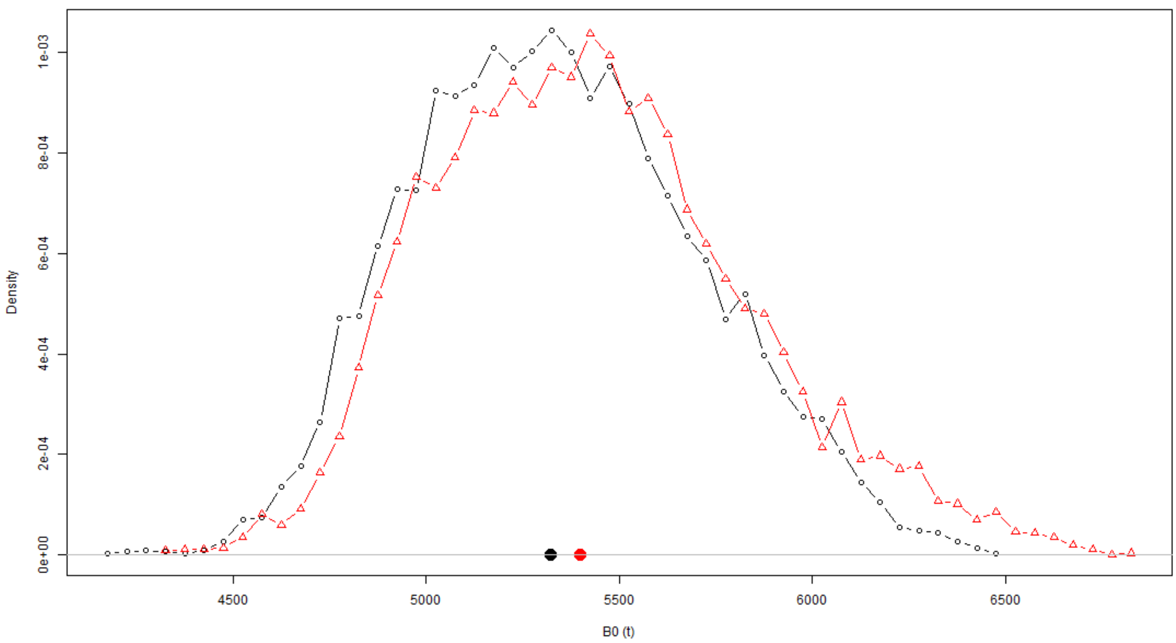

Figure C18: Western stock, base: histograms of B_0 for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (at approximately B_0 = 5320 t and 5400 t).

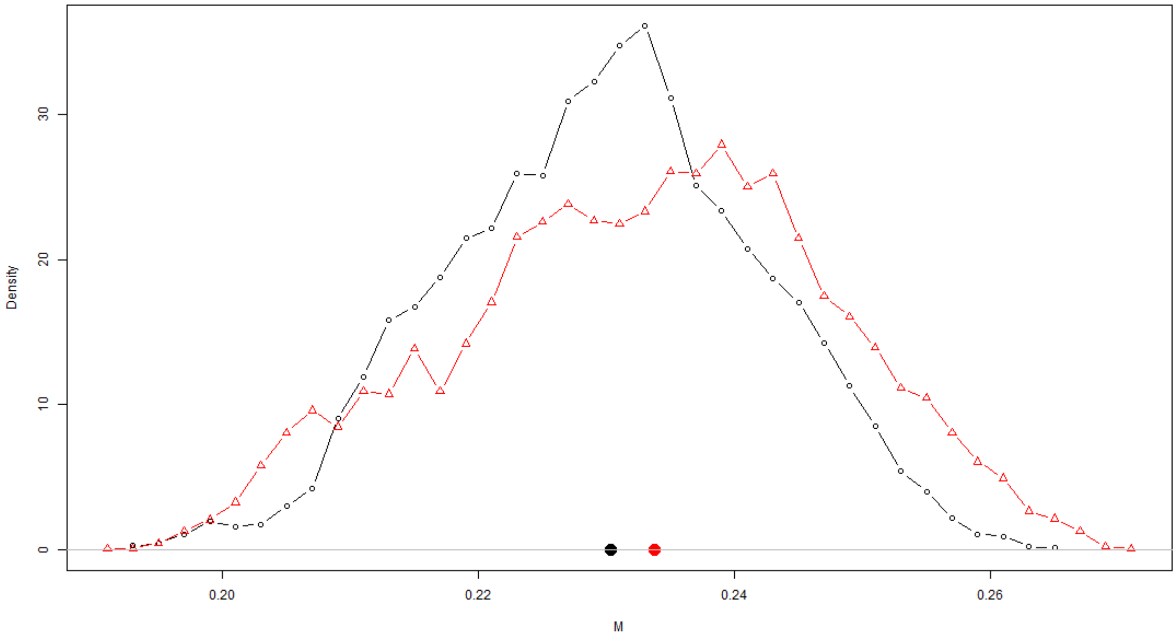

Figure C19: Western stock, base: histograms of M for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (at approximately M = 0.230 and 0.234).

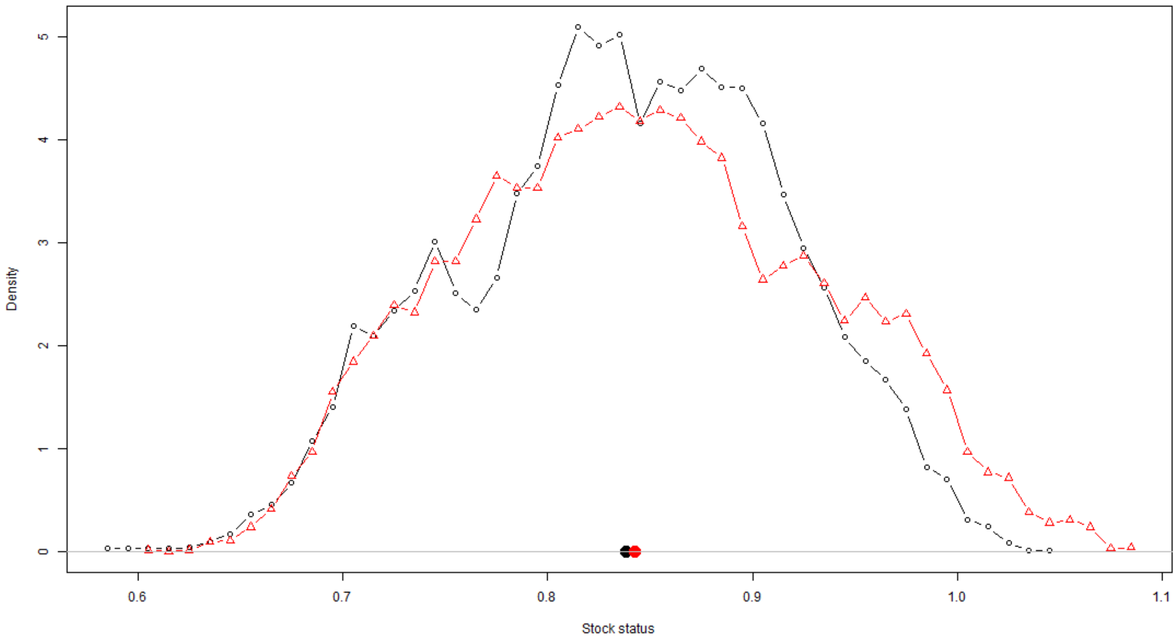

Figure C20: Western stock, base: histograms of 2018 stock status (B_{2018}/B_0) for the first half of each chain combined (black) and the second half of each chain combined (red). The medians for each histogram are marked by the solid circles (both at approximately 0.84).

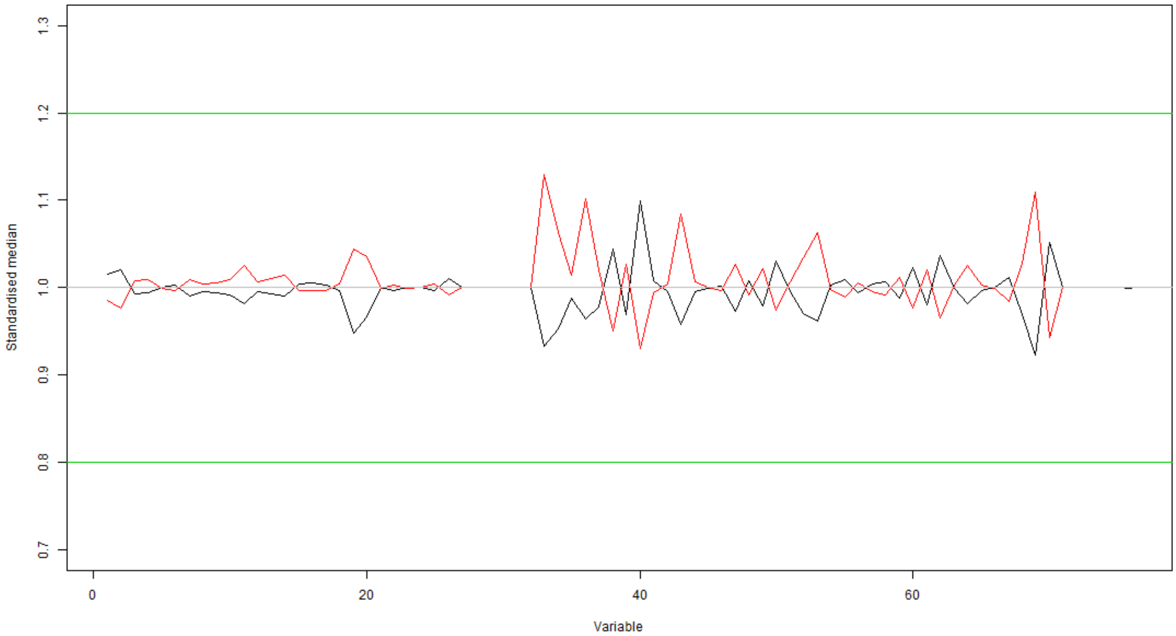

Figure C21: Western stock, base: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for each free parameter estimated. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).

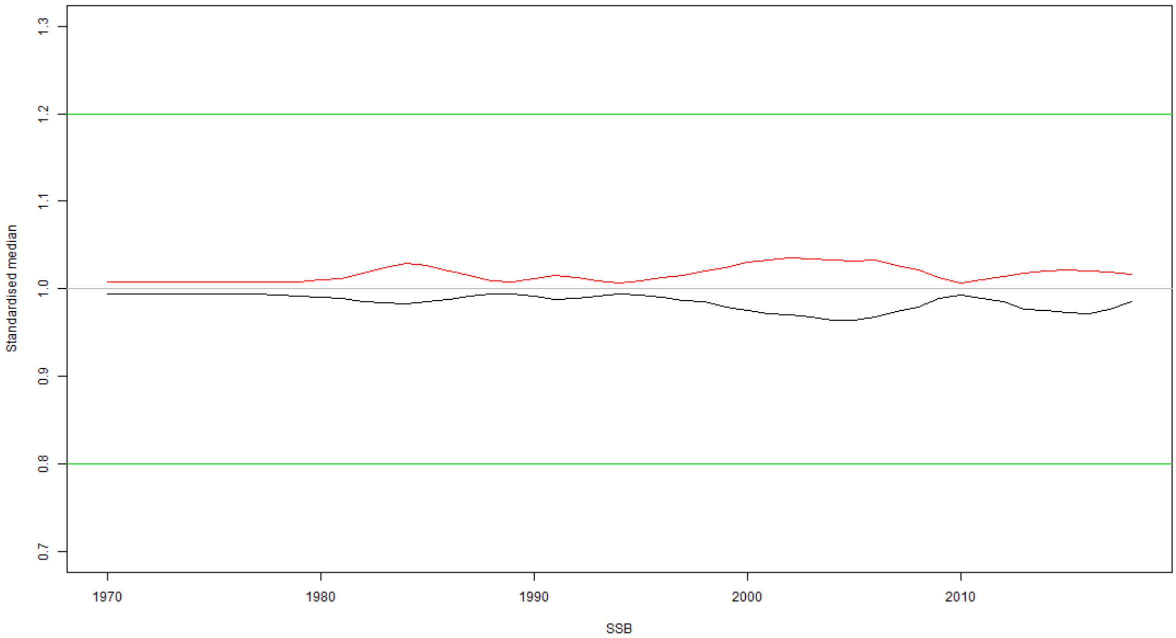

Figure C22: Western stock, base: standardised medians for the first half of each chain combined (black) and the second half of each chain combined (red) for SSB from 1970 to 2018 inclusive. The medians for each half (combined across chains) are standardized by dividing by the median over the full length (combined across chains).