Revised Base-Case Results for 2010 Stock Assessment of Aurora Trough Macquarie Island toothfish, using data up to and including July 2009.

Gavin Fay[1], Malcolm Haddon[1], and Geoff N. Tuck[1]
[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, Tasmania, Aust.
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Enquiries should be addressed to:
Gavin Fay
CSIRO Marine and Atmospheric Research
GPO Box 1538, Hobart
Tas 7001, Australia
Tel: 61-3-6232-5321
Fax: 61-3-6232-5053
Email: gavin.fay_at_csiro.au

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1. NON-TECHNICAL SUMMARY

This paper presents the results of a revised base-case analysis of the Aurora Trough stock assessment using Stock Synthesis, following discussions by the Sub-Antarctic Resource Assessment Group (SARAG) on Tuesday March 16th, 2010. The base-case decided by SARAG was to use the following assumptions/parameterizations:

1. value for the rate of natural mortality, *M*, of 0.13 yr^{-1},

2. use of the sex-specific growth curve parameters estimated by Constable et al. (2001),

3. length at 50% maturity of 89cm,

4. exclusion of tag recaptures in the year of release from the likelihood,

5. including over-dispersion in the tag-recapture likelihood,

6. a tag detection rate for the longline fleet of 0.94, the average of the annual values estimated for the trawl fleet

While the sensitivity analyses in the 2010 Aurora Trough stock assessment document (Fay 2010) explored the effect of these assumptions, they were not included together in the same analysis. Updated results of applying this version of the model, and key sensitivity analyses from this revised base-case are therefore presented. The catch level for 2010/11 is calculated under the CCAMLR control rule, following application of Markov Chain Monte Carlo (MCMC) methods to characterize uncertainty in the parameter estimation. The constant catch satisfying the CCAMLR rule is calculated assuming that future catches are taken solely by trawl, or solely by longline.

Inclusion of an over-dispersion term when modelling the tag-recaptures leads to a lower penalty being applied to a lack of recaptures from tagged fish released in the last few years. Consequently, the result of including this over-dispersion is a smaller current stock size than when tag recaptures are assumed to be completely random. Data are insufficient to estimate individual over-dispersion parameters for each tag group and so the over-dispersion parameter is fixed at the median of the estimates for those tag groups for which data are available.

The new base-case estimates current (2010/11) spawning biomass to be 2,004t or 54% of unfished spawning biomass. The new base-case estimate for current (2010/11) trawl available biomass is 2,920t. Trawl available biomass is estimated to be well above 66.5% pre-tagging (1995) levels, which had previously been used as the limit reference point for the Aurora Trough toothfish fishery.

The projected catch for 2010/11 under the CCAMLR control rule using the revised base-case is 140t. The magnitude of this catch is increased to 164t when the projected catches are assumed to be taken solely by longline instead of trawl. The catch levels under the CCAMLR control rule are, not surprisingly, similar to those calculated under an equilibrium F50 strategy (ie fishing at a constant harvest rate at the level expected to result in an equilibrium level of 50% unfished spawning biomass), which are 145 and 173t if catches are taken purely by trawl or longline respectively.

2. INTRODUCTION

This paper presents results of a revised base-case for the integrated stock assessment of Aurora Trough Patagonian toothfish (*Dissostichus eleginoides*) at Macquarie Island to 2010/11 using data collected up until and including July 2009. The revisions are based on discussion of the analyses in Fay (2010), discussed at the 38th meeting of the SARAG on Tuesday March 16th, 2010. 2010/11 catch levels, for provision of advice in determining the 2010/11 TAC are calculated based on these revised base-case results.

Aside from the assumptions discussed below, the analyses presented here use the same approach, data, and model parameterizations as discussed in Fay (2010).

3. BASE-CASE ANALYSIS

3.1 Revised assumptions

The assumptions that the revised base-case analysis are based on were explored during sensitivity analyses in Fay (2010), although the consequence of their simultaneous application were not addressed in a single analysis. Model parameters not mentioned below were assumed to be the same as in the previous base-case scenario presented in Fay (2010). Specifications for the new base-case, as determined by SARAG, are as follows:

1. the value for the rate of natural mortality, M, to be fixed at 0.13 yr^{-1},

2. use of the sex-specific growth curve parameters estimated by Constable et al. (2001),

3. a length at 50% maturity of 89cm, as used in previous integrated stock assessments (*e.g.* Tuck et al. 2006) of Aurora Trough toothfish,

4. exclusion of tag recaptures in the year of release from the likelihood,

5. including over-dispersion in the tag-recapture likelihood, allowing for ‘clumping’ in the numbers of tag recaptures,

6. fixing the tag detection rate for the longline fleet at 0.94, which is an average of the annual values estimated for the trawl fleet.

3.2 Over-dispersion in tag recaptures

Accounting for clumping in the tag returns requires the inclusion of an over-dispersion parameter. This term relates to the variability of the observed data, which is greater than that expected if the tags were recaptured randomly. Including over-dispersion in the tag recaptures is implemented by assuming that the recaptures are distributed according to a negative binomial instead of Poisson. The degree of over-dispersion relative to the Poisson is handled by an additional parameter for each tag group, potentially resulting in an additional 61 parameters (over the 37 previously) to be estimated. Estimating over-dispersion parameters allows for clumping in the tag recapture data, or less of a penalty on the model fit given more (or less) recaptures than predicted from a tag group in a given year.

Allowing the over-dispersion parameters to vary by tag group resulted in an improved fit to the tag recapture data (Table 1). However, a lack of information from some of the tag groups means that there is considerable uncertainty regarding the values for these parameters which is not accounted for in the point estimate. The distribution of point estimates for the over-dispersion parameter (Figure 1) is different from that obtained when the uncertainty is taken into account through application of MCMC methods (Figure 2). The posterior medians of the over-dispersion parameters for some tag groups move toward a larger value, revealing a lack of information in the data regarding the value for these parameters, and the influence of the (flat) prior distribution. The consequence is a lower estimated biomass than predicted by the point estimate. Indeed, when individual over-dispersion parameters are estimated, the MCMC chain fails to converge, and the point estimate for the time series of spawning biomass lies well outside the 95% CI from the posterior distribution (Figure 3). This suggests that the point estimates for at least some of the over-dispersion parameters are not appropriate. Perhaps more importantly, the uncertainty in these estimates is poorly represented. This produces problems when running the MCMC chain to characterize the uncertainty around the assessment results.

The tag-recaptures are not returned randomly so it is recognised that over-dispersion in the tag recaptures should be included in the assessment. However, there is clearly insufficient tagging data to enable the valid estimation of individual over-dispersion parameters for each tag group, which would be the ideal when attempting a full characterization of the uncertainty associated with the tag-recapture data. Assuming the aggregation of tag returns is a reflection of the behaviour of the tagged fish, it is reasonable to assume that there should be some similarity to the over-dispersion expressed by different tag groups (e.g. all fish tagged in the same year should have the same value, or all fish of a given age, etc.). Indeed, for those tag groups where there appeared to be sufficient information to estimate the value of the over-dispersion parameter, the posterior distributions were very similar. In the absence of sufficient data to estimate individual parameters for each tag group a different solution is required. Using a Poisson distribution is effectively assuming an over-dispersion parameter of 1.0, that is a constant value across all groups. As an alternative, it is proposed that, to generate a viable base-case, all over-dispersion parameters are assumed to take the same value, with this value being pre-specified at the median of the estimates from those tag groups which appeared to have sufficient information to estimate them from the MCMC. Computationally, it is not currently possible in Synthesis to estimate 1 parameter and have the other tag groups take this value. Working with the useable results from the MCMC generates 2 estimates of the over-dispersion parameter, one from the point estimates (1.9) and one from the posterior medians (5.8). The latter is higher due to the consideration of uncertainty, although the value is likely heavily influenced by the choice of prior. The impact of assuming a single value on the model fit is considered, and a likelihood profile across different values for the parameter constructed.

3.3 Quantification of uncertainty

Variances for the estimates of the model parameters and derived quantities of interest can be determined either by using asymptotic standard errors based on inverting the hessian matrix (as reported in the 2010 Aurora Trough stock assessment report, Fay 2010), or by applying Markov-Chain Monte Carlo (MCMC) methods (e.g. Hastings, 1970; Gilks et al., 1996; Gelman et al., 1995). The Metropolis-Hastings variant of the MCMC algorithm was used to sample 1,000 equally likely parameter vectors from the joint posterior density function for the base-case. This sampling process implicitly considers uncertainty in all dimensions of parameter space, and accounts for correlation among model parameters. The samples on which inference is based were generated by running 1,500,000 cycles of the MCMC algorithm, discarding the first 500,000 as a burn-in period and selecting every 1,000th parameter vector thereafter. A potential problem with the MCMC algorithm is how to determine whether convergence to the actual posterior distribution has occurred. Standard diagnostic statistics developed by Geweke (1992), Heidelberger and Welch (1983), and Raftery and Lewis (1992), and the extent of auto-correlation among the samples in the chain were used to determine whether there was a lack of convergence in the chain.

3.4 Projection under the CCAMLR control rule

In addition to the deterministic projections from the base-case results, the sample from the posterior distribution for the base-case was used to conduct stochastic projections given both parameter uncertainty and uncertainty in future recruitment events, in order to calculate the 2010/11 catch given implementation of the CCAMLR control rule, where next year's catch is the constant catch such that:

- the probability that spawning biomass will fall below 20% of the pre-exploitation level over the 35 year projection period does not exceed 0.1; and

- the median escapement for the Fishery of the spawning biomass shall not be less than 50% over a 35 year projection..

The sampled posterior was therefore projected forward 35 years under a range of constant catch scenarios in order to find the maximum catch level that satisfies both criteria.

4. RESULTS

4.1 Diagnostics

Diagnostic plots for the various sources of data are shown in Figure 13 through Figure 18 in Appendix A. These plots are included for completeness, in that they represent the new base-case. Little attention is paid to these plots in discussion as this is covered in the assessment document (Fay 2010).

4.1.1 Tag recapture data

As reported in Fay (2010), estimating over-dispersion parameters results in an improved fit to the tag recapture data. The estimated values for the degree of over-dispersion varied considerably among tag groups, although tag groups for which there has been a long or positive recapture history were generally estimated to have low over-dispersion. The estimation of large values for the degree of over-dispersion for some of the recent tag groups reflects the fact that there have been few (or no) recaptures from these groups as of yet (Figure 1).

Assuming a fixed value greater than 1 for the over-dispersion parameters also results in an improved fit to the tag recapture data over that obtained when assuming Poisson (or that the over-dispersion parameters are fixed at 1), with only 25 units of log-likelihood difference between the fit at a value of 1.9 compared with that obtained when estimating the additional 61 parameters Table 1 (as a rough guide, each extra parameter should improve the log-likelihood by approximately 1.92 units so 61 parameters giving an improvement of only 25 would normally be rejected as a modelling option). Examining the likelihood profile across different fixed values for the over-dispersion parameter, when all tag groups are assumed to have the same value, the best fit (lowest value for the negative log-likelihood) is obtained with an over-dispersion value of 2.15, however a value of 1.9 is well within the approximate 95% confidence interval (Figure 4, portion of the curve below the dotted horizontal line). Figure 4 also demonstrates how much an improvement over the assumption that the recaptures are Poisson (over-dispersion = 1) is, as the model fit at this value lies well outside the 95% confidence interval. Similarly, the larger degree of over-dispersion indicated by the poorly converged posterior medians (5.8) is a poor representation of the data, as the fit obtained under this scenario also lies well outside the interval.

4.1.2 MCMC diagnostics

Figure 5 summarises the values of five statistics (the ratio of the batch standard deviation to the naive standard deviation, the extent of lag-1 auto-correlation, the *p*-value computed from the Geweke statistic, whether the Heidelberger and Welch test is passed or not, and the value of the single-chain Gelman statistic) used to diagnose non-convergence of the MCMC chain for the model parameters. Ideally, the value of the first statistic should be close to 1, the value of the second statistic should be close to zero, the value of the third statistic should be greater than 0.05, and the value of the last statistic should be less than 1.05. There appears to be some evidence for a lack of convergence for a couple of the parameters given the distribution for the lag-1 autocorrelation (Figure 5), most notably the 1994 recruitment deviation. This is not surprising given the expected low mixing rate for this parameter due to the precision of its estimate compared to other recruitments. This perhaps indicates that it might be necessary to run the MCMC algorithm for longer and increase the thinning coefficient, however the likely influence of this on overall model results is negligible.

4.2 Base-case results

4.2.1 Selectivity and Recruitment

The estimated selectivity patterns (Figure 6) and the estimates for the time-series of recruitment (Figure 7) are much the same as reported in the original assessment (Fay 2010). The recruitment time series shows pulses of recruitment in 1980, 1987, 1994, and 1998/99, although estimation of individual recruitment events is generally uncertain (Figure 7).

4.2.2 Biomass and fishing mortality estimates

Under the revised base-case, current (2010/11) trawl available biomass (calculated as mid-season available biomass) is estimated to be above pre-tagging levels (Figure 8), with the time series clearly showing the impact of the fishery in the 1990s, and subsequent recovery in biomass following closure. 2010/11 available biomass is estimated to be 2,920t (Table 1).

Model estimates of current (2010/11) and unfished spawning biomass are given in Table 1. The base-case indicates that current spawning biomass is at 54% of unfished conditions. Uncertainty estimates indicate some probability that the stock may currently be below the management target of 50% unfished spawning biomass (Figure 9). Figure 10 shows the time series of Spawning Potential Ratio (SPR) for the base-case as a measure of fishing intensity, and reveals that the fishing pressure from 2005-2008 is estimated to have been greater than that which would on average have been required to reduce the population to below 50% unfished spawning biomass (Figure 10, points below red dashed horizontal line).

4.2.3 2010/11 catch levels

The maximum constant catch level by trawl that satisfies both the CCAMLR criteria was 140t. Under this catch, median spawning biomass is just above 50% unfished levels after the 35 year projection, with a zero probability of the stock being reduced below 20% unfished spawning biomass during this period given the 1,000 vectors of spawning biomass obtained from the sample of the posterior distribution. Figure 11 summarises the posterior distribution for the time series of spawning biomass and spawning stock depletion (spawning biomass relative to unfished). If the catch over the 35 year projection period is assumed to be taken by longline instead of trawl, then the constant catch satisfying the CCAMLR control rule criteria is 164t.

Catches of 140t and 164t under the CCAMLR control rule are consistent with the long-term catches under a constant F50 harvest rate policy, calculated under the base-case to be 145t for catches by trawl only and 173t if catches were by longline (Table 1).

4.3 Sensitivity analyses

The results of a small number of key sensitivity tests to the new base-case are presented in Table 1.

4.3.1 Maturity

Using the larger estimates of length-at-maturity from analysis of new data (Fay 2010, length of 50% maturity of 139cm) has little impact on both the fit to the data and the results, other than that the absolute values for the spawning biomass are unsurprisingly estimated to be lower under this scenario.

4.3.2 Tagging Data

As with the results in Fay (2010), there was very little difference in the available biomass estimates dependent on the method for assigning ages to tag-released fish (Table 1). Estimates of current spawning biomass relative to unfished were higher than the base-case when assuming a single age at release for all fish tagged in a given year, and lower when disaggregating the data into lots of ages of release per year.

A larger, less depleted spawning stock is estimated when the tag recaptures obtained within the year of release are included in the model (Table 1). However, including these recaptures is probably not appropriate in an annual model as they likely are reflective of season length rather than exploitation rate and so are not comparable from year to year.

Increasing the tag detection rate for the longline fleet to 100% (instead of the base-case 94%) resulted in almost negligible change to the model results (Table 1).

The model results are also clearly affected by the value chosen for the degree of over-dispersion in the tag recaptures (whether they are allowed to depart from random and be clumped), with the uncertainty characterised by the likelihood profile in Figure 4. Increasing levels of over-dispersion are associated with a smaller estimated current spawning stock size, and also lower spawning stock size relative to unfished levels (Table 1). The impact of the value for the over-dispersion parameter on the estimate of the F50 catch by trawl is shown in Figure 4. The profile suggests very little change in the 2010/11 catch over the range of values for the over-dispersion parameter contained within the approximate 95% confidence interval (1.8-2.6). Fixing the over-dispersion parameters at 5.8 results in a lower catch than the revised base-case with the F50 catch being 118t by trawl and 141t by longline in this case.

5. DISCUSSION

The new, revised base-case analysis incorporates the changes suggested by SARAG.

1. Under the new base-case, the current (2010/2011) trawl available biomass is estimated to be well above the limit reference point of 66.5% pre-tagging (1995) levels, with the base-case trawl available biomass estimated to be 2,920t. Spawning biomass is estimated to currently be 54% of unfished spawning biomass, with the base-case estimate of 2010/11 spawning biomass being 2,004t.

2. Under the CCAMLR control rule, the calculated catch for 2010/11 is 140t, assuming that future catches are taken by trawl.

3. The inclusion of over-dispersion in the tag recaptures is problematic in that there is insufficient information to estimate these parameters individually. Consequently, uncertainty in the value for the degree of over-dispersion is not incorporated when conducting the MCMC. Inclusion of over-dispersion is an improvement over assuming that recaptures are purely Poisson (as evidenced by the likelihood profile in Figure 4). Fixing the value for all tag groups at a level suggested by the data, as implemented here, is therefore suggested as better than ignoring the effect, even if full characterisation of the uncertainty is not possible. Results of sensitivity analyses suggest that there will be little change to the calculated 2010/11 catch levels given the range of values for over-dispersion that remain consistent with the data. Planned developments to the Synthesis software include more comprehensive control over the parameters controlling tagging, and it is envisaged that this will allow improvement in the way the over-dispersion is handled without resorting to the over-parameterised case of individual parameters by tag group.

4. The new, revised base-case uses the previously implemented length at 50% maturity of 89cm. Analyses of recently collected data from longline suggest that this size at maturity may be larger – the results of which on the assessment are to estimate a smaller spawning

stock size. However, there is little impact on the calculated long-term F50 catch when this is assumed to be taken by trawl.

5. The value assumed for the tag detection rate had almost no impact on the model results. This is because longline fishing in the Aurora Trough has so far been minimal. If the data from Aurora Trough continue to be derived from longline fishing operations, then the value for the detection rate will become more influential to the assessment.

6. Additional assumptions regarding the treatment of tagging data did impact the model results. Decreasing the time assumed to allow for mixing of tag releases within the rest of the population resulted in higher estimates of both available and spawning biomass. The base-case assumption to remove the recaptures in the year of release from the likelihood function is probably most appropriate for a model that operates on an annual basis, as this removes the effect of variability in season length on the results. That is, if the annual catch is spread out over a longer period, one might expect more recaptures of fish tagged within that season than a shorter season, which would not be a result of differences in the harvest rate.

6. ACKNOWLEDGEMENTS

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Table 1 : Results of the revised base-case and sensitivity analyses, with estimates of the trawl available biomass, spawning biomass, 2010/11 catch, and the contributions to the negative logarithm of the likelihood function. Values in the latter columns in italics indicate values not comparable with those in the base-case.

	Trawl available biomass (TAB)			Spawning biomass			F50 yield at $0.5SB_0$ (t)		negative log-likelihood					
	2010/11	pre-tagging (1995)	2010/1995	$SB_{2010/11}$	SB_0	$SB_{2010/11}/SB_0$	trawl	longline	Total	Length	Age	Tag comp	Tag Recap	Rec't
Base-case (over-dispersion = 1.9)	2,920	2,465	1.18	2,004	3,709	0.54	145	173	1156.1	488.1	65.6	5.00	598.1	-0.77
Maturity														
length at 50% mature 139cm	2,939	2,459	1.19	840	1,428	0.59	137	157	1156.1	488.2	65.6	5.00	598.1	-0.81
Tag-recapture data														
individual overdispersion parameters	2,685	2,476	1.08	2,001	3,704	0.54	144	172	1130.3	487.8	65.6	4.99	572.9	-1.25
no overdispersion in tag recaptures (Poisson)	2,900	2,343	1.24	1,919	3,598	0.53	141	169	1199.7	489.1	66.0	5.00	640.0	-0.40
overdispersion = 2.15	2,856	2,459	1.16	1,973	3,673	0.54	143	172	1155.3	488.0	65.6	5.00	597.6	-0.87
overdispersion = 5.8	1,915	2,167	0.88	1,401	3,014	0.46	118	141	1191.6	487.8	65.7	5.01	634.7	-1.66
include recaptures in year of release	3,521	3,162	1.11	2,709	4,476	0.61	173	207	*1315.9*	487.9	64.2	5.20	*759.8*	-1.24
longline tag detection rate = 100%	2,937	2,467	1.19	2,011	3,717	0.54	145	174	1156.8	488.1	65.6	5.04	598.7	-0.75
1 tag group per year, fix age of release (9, 12)	3,064	2,664	1.15	2,263	4,000	0.57	155	186	*787.3*	487.6	65.3	4.94	*230.5*	-1.01
1 tag group per year, age of release varies	3,088	2,640	1.17	2,256	3,983	0.57	154	185	*791.4*	487.7	65.4	4.90	*234.3*	-0.86
lots of tag groups per year (release lengths)	2,764	2,355	1.17	1,829	3,505	0.52	137	164	*1426.3*	488.3	65.7	5.00	*867.9*	-0.65

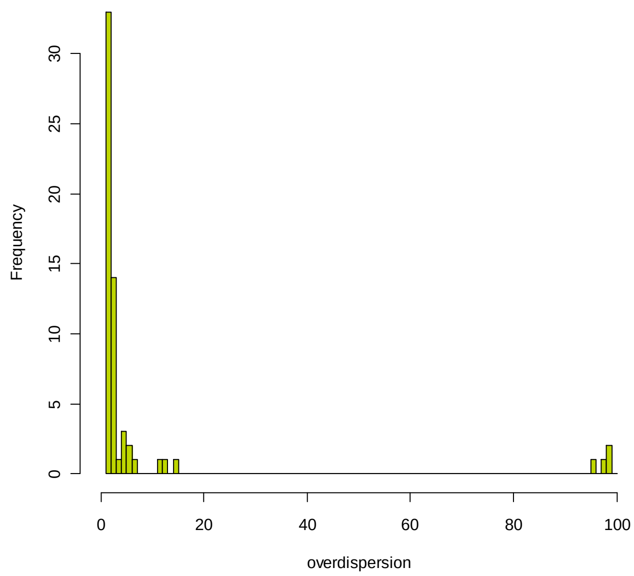

Figure 1 : distribution of the estimates for the over-dispersion parameters. A value close to 1 indicates low over-dispersion (recaptures are effectively Poisson distributed), whereas values greater than 1 indicate higher degrees of over-dispersion.

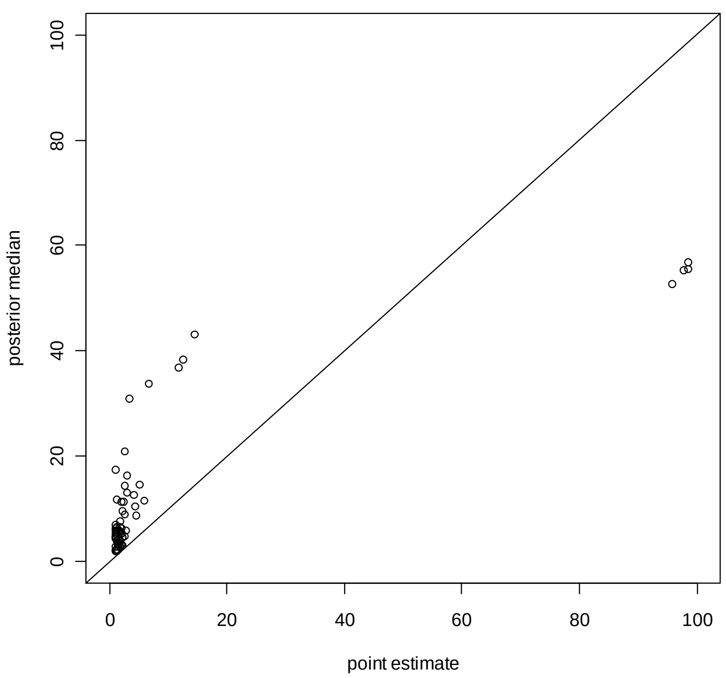

Figure 2 : Compariosn of over-dispersion parameter estimates from the point estimate (x axis) and the value for the posterior median (y axis).

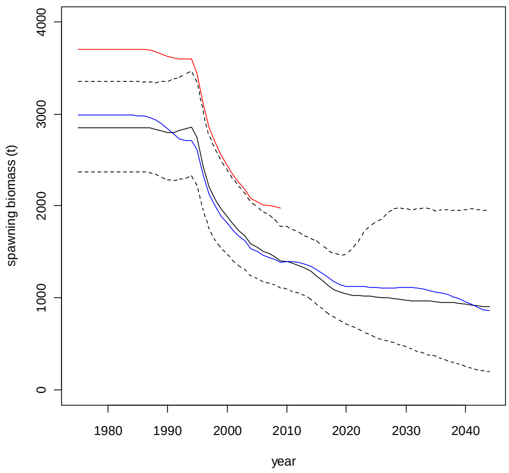

Figure 3 : posterior median (black line) and 95% CI for a version of the revised base-case with estimation of individual over-dispersion parameters for each tag group. Red line indicates the point estimate, which is well outside the 95% interval for this (poorly determined) scenario. Blue line is the vector from the posterior sample that gives the best fit to the data.

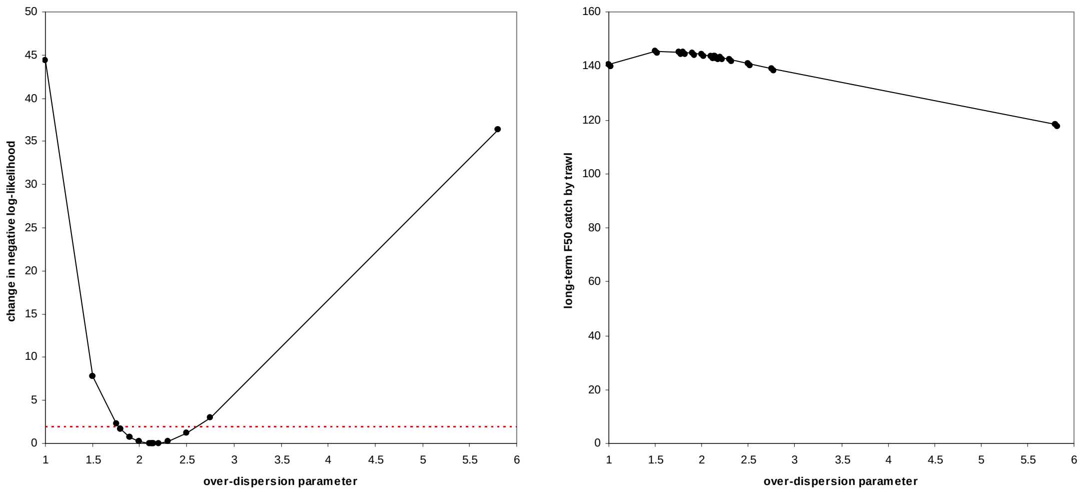

Figure 4 : Likelihood profile for the value of the over-dispersion parameter when the same value is assumed for all tag groups. Red dotted line indicates the approximate 95% confidence interval – points on the black line below the red line lie within the interval. Right panel shows the impact on the estimate of the long-term trawl catch under an F50 strategy (approximately equal to the catch under the CCAMLR rule) with changing the value for the over-dispersion parameter.

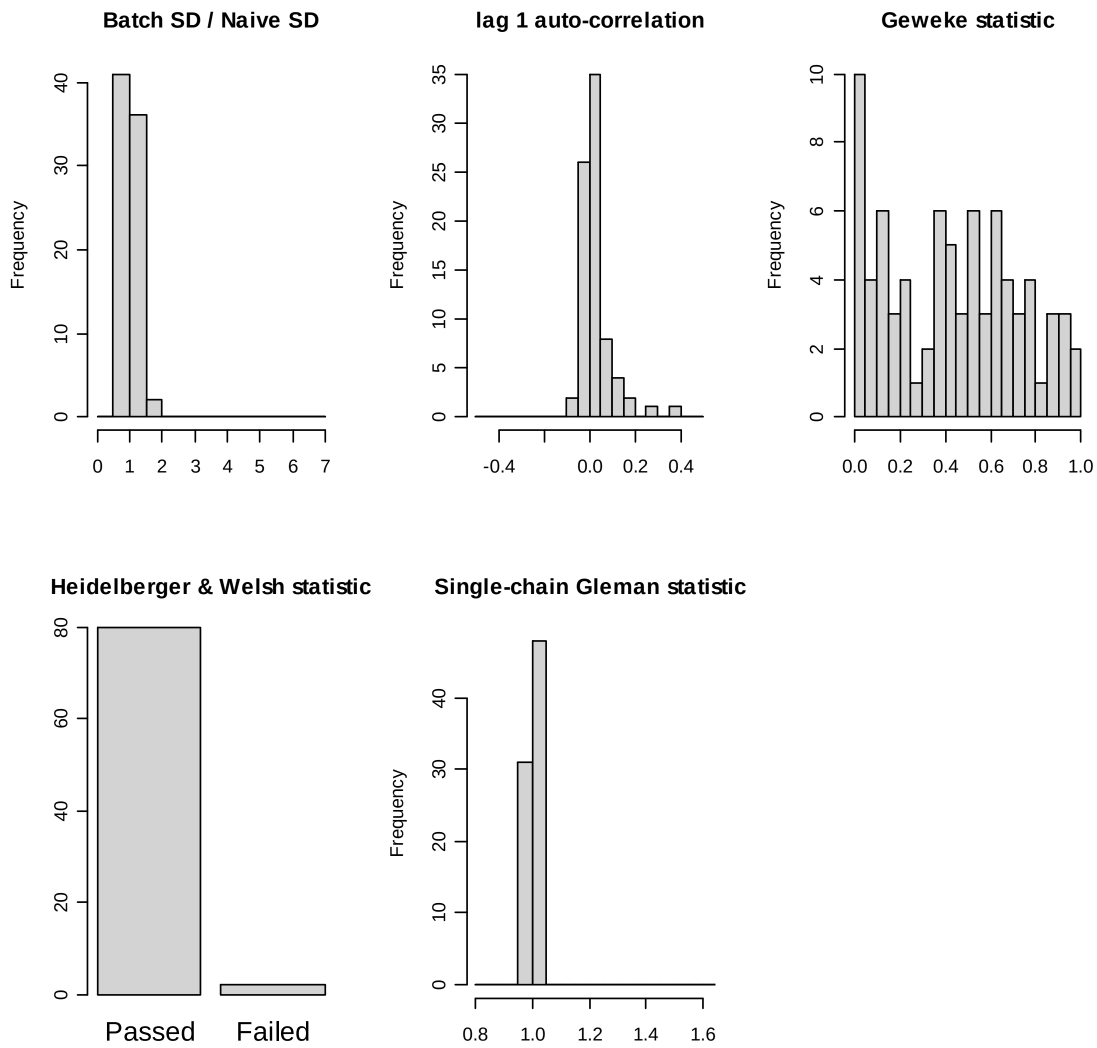

Figure 5 : MCMC diagnostic statistics for the revised base-case model parameters

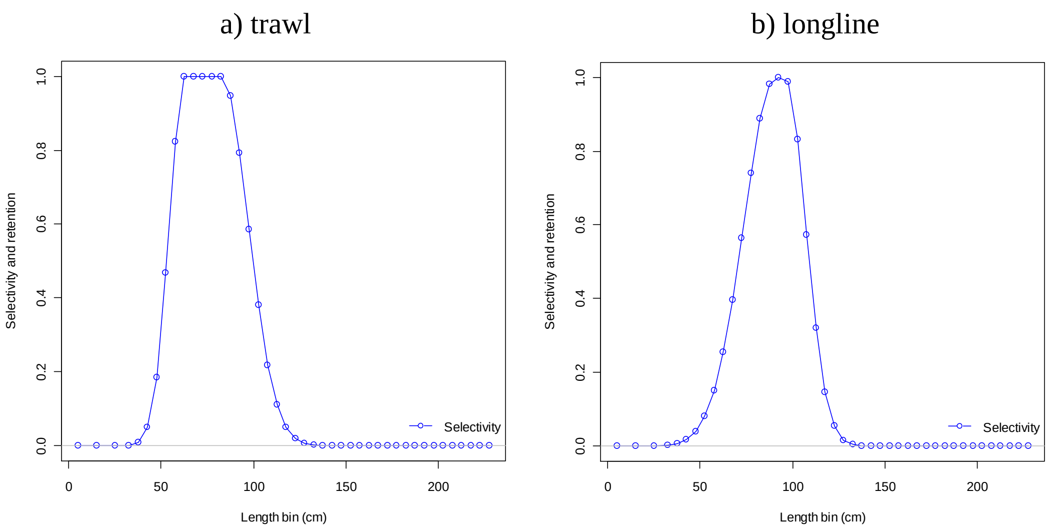

Figure 6 : Base-case estimates of selectivity at length for trawl and longline.

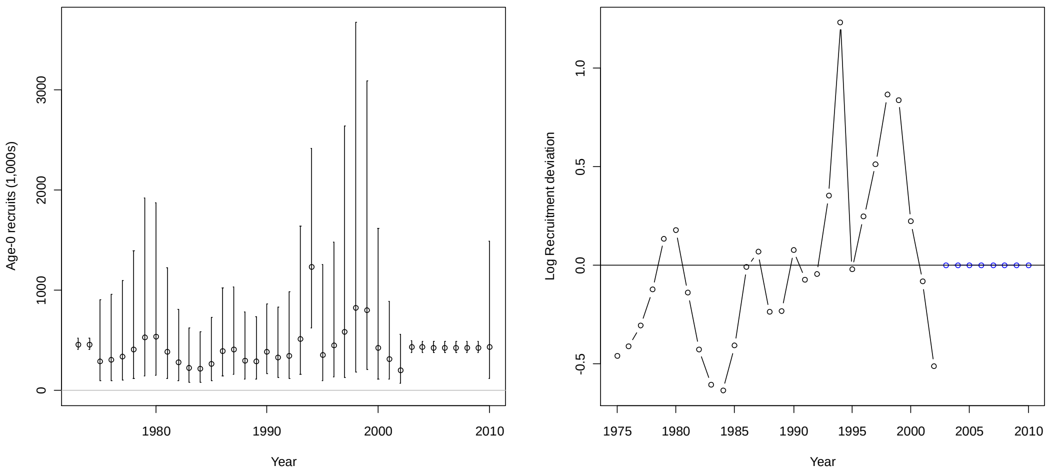

Figure 7 : base-case time series of estimated recruitments and recruitment residuals. The bars in the left hand graph depict the 95% percentile confidence intervals computed from the asymptotic standard errors.

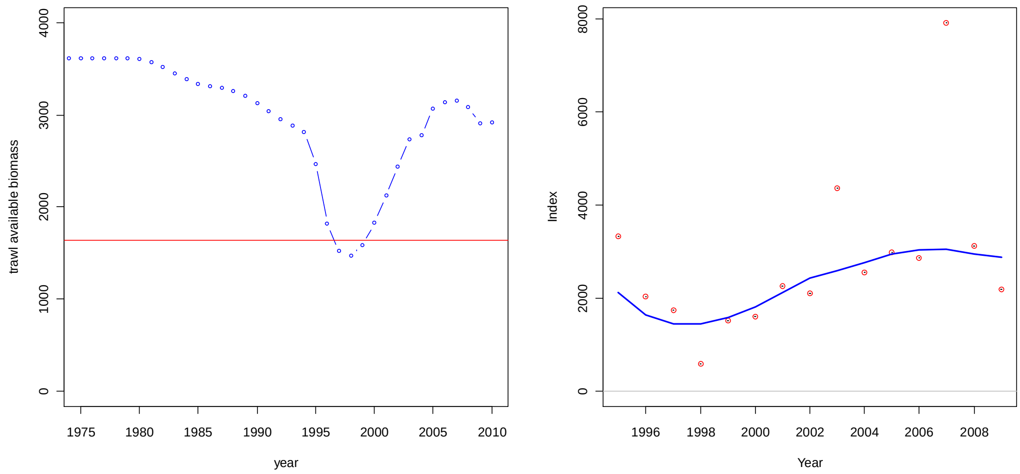

Figure 8 : Base-case estimated time series of the trawl available biomass (left panel). Horizontal red line indicates 66.5% of pre-tagging (1995) available biomass. Right-hand panel compares the base-case estimate (blue line) with the 2009 tag-only assessment results (red points).

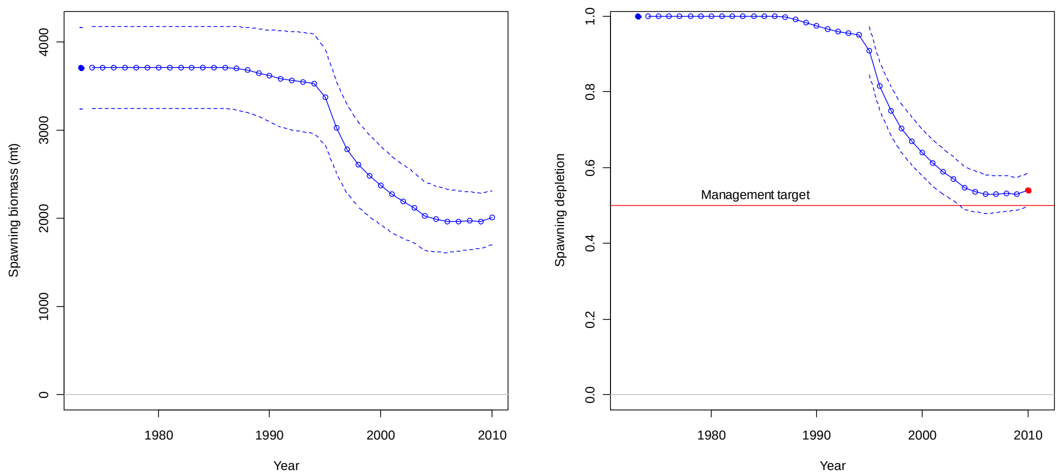

Figure 9 : Base-case estimates for the time series (with approximate 95% confidence intervals) of spawning biomass (left panel), and spawning biomass relative to unfished (1975) conditions (right panel, denoted spawning depletion).

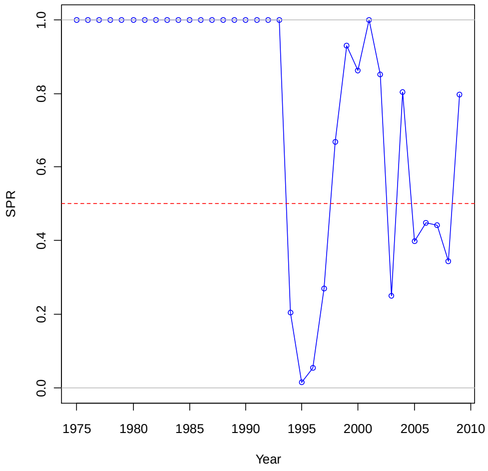

Figure 10 : Time series of spawning potential ratio (SPR). The red horizontal dashed line indicates an SPR value of 0.5. If the value for SPR is below this line this indicates that the rate of fishing mortality in that year was likely greater than that which on average results in a spawning biomass of 50% unfished levels.

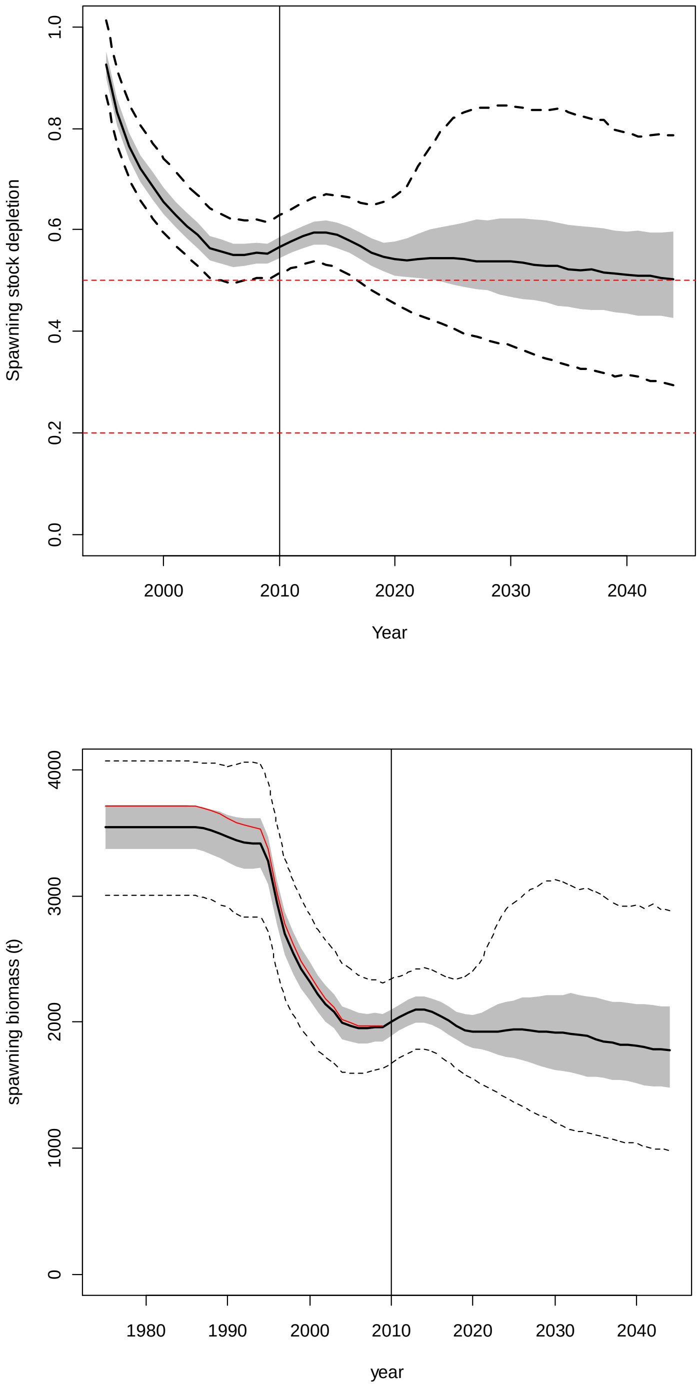

Figure 11 : Summary of the posterior distribution for the projected spawning stock depletion and spawning biomass given a constant annual future catch of 140t by trawl. Plotted are the median (black solid line), central 50% (grey shaded area), and 95% (dashed lines) credibility intervals. Black vertical line indicates the beginning of the projection period, horizontal dotted lines indicate the management target of 50% unfished spawning biomass and the limit reference point of 20% spawning biomass. Red solid line on spawning biomass panel indicates the time series of spawning biomass obtained from the point estimate.

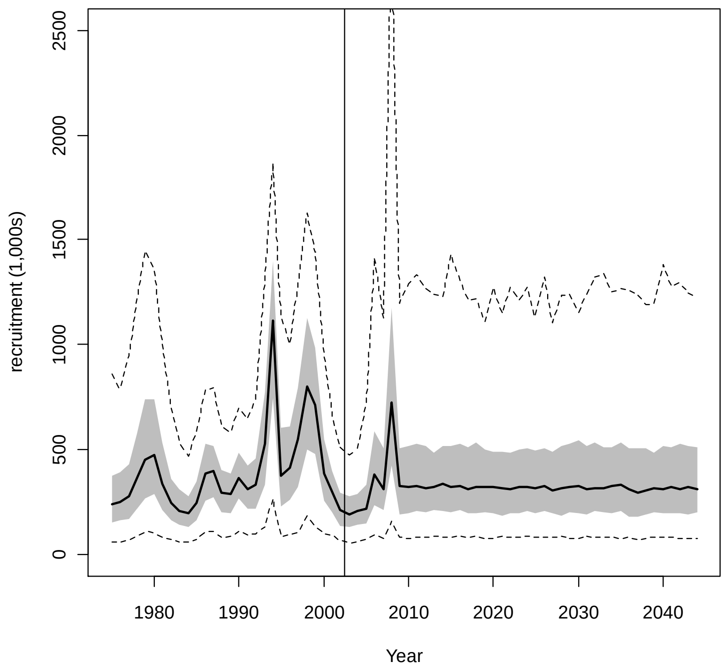

Figure 12 : Summary of the distribution (shading as per Figure 11) for the time series of recruitment obtained from the posterior.

8. APPENDIX A

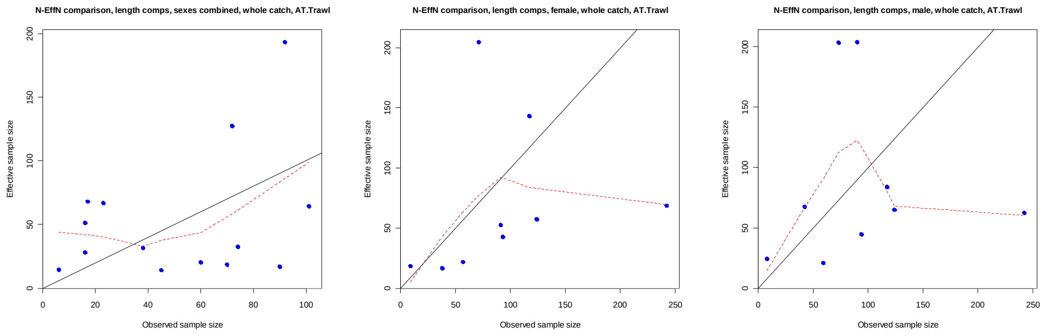

Figure 13 : Input versus effective sample size for the trawl length composition data.

a) sexes combined

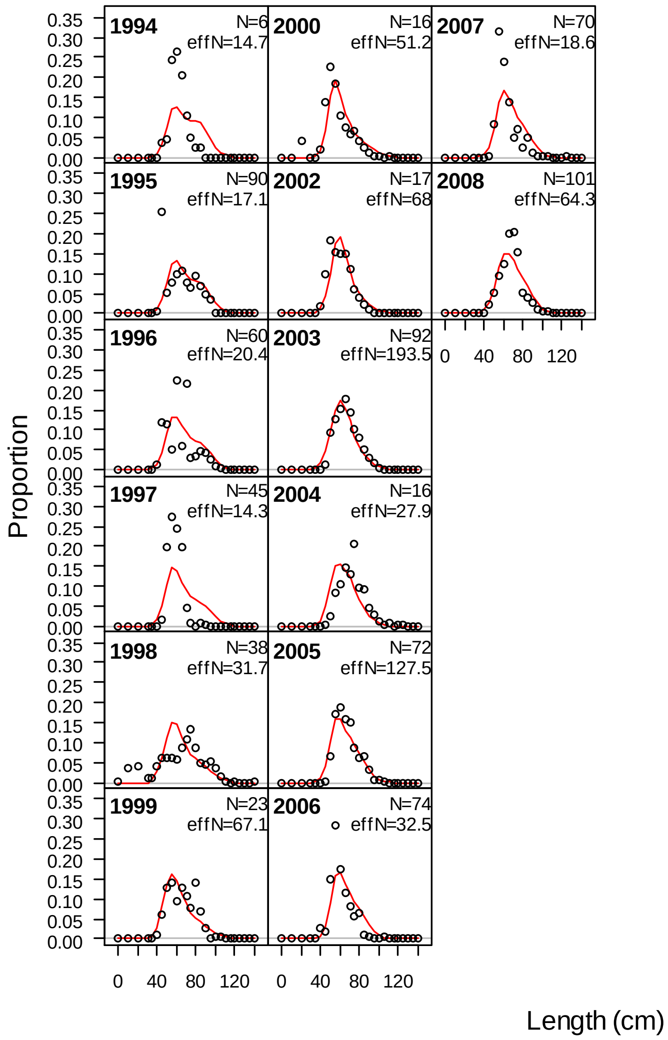

Figure 14 : Base-case fits to the Aurora Trough trawl length composition data

b) female

c) male

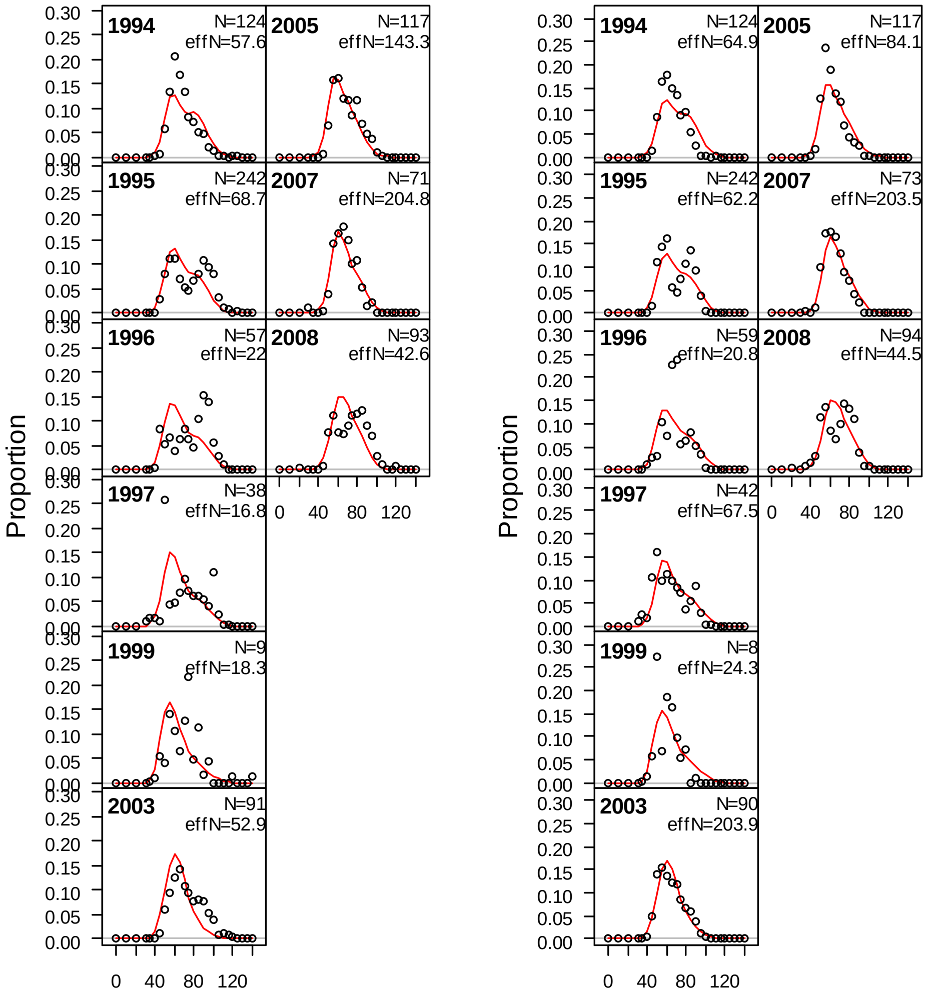

Figure 14 continued.

a) sexes combined

b) female

c) male

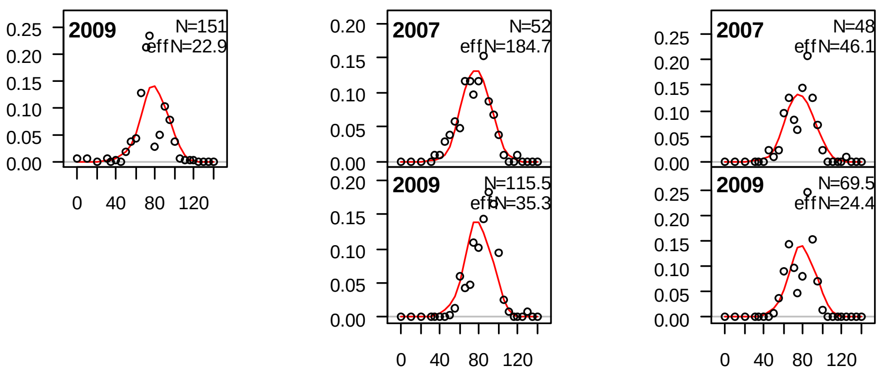

Figure 15 : Base-case fits to the longline length composition data.

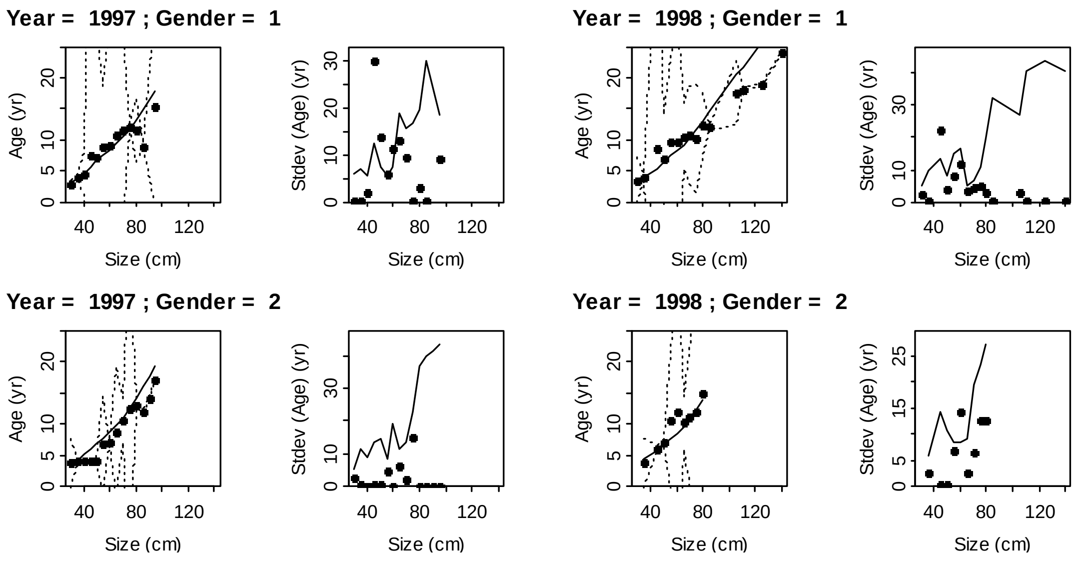

Figure 16 : Diagnostic plots for the fit to the condiitional age at length data. For each year and gender (1=female, 2=male), the two panels are 1. Mean age-at-length by size-class (observed and predicted) and the 90% CIs based on adding 1.64 SE of mean to the data, and 2. SE of mean age-at-length (observed and predicted) and the 90% CIs based on the chi-square distribution. The dots are the data, the dotted lines the 90% CIs and the lines the expected values.

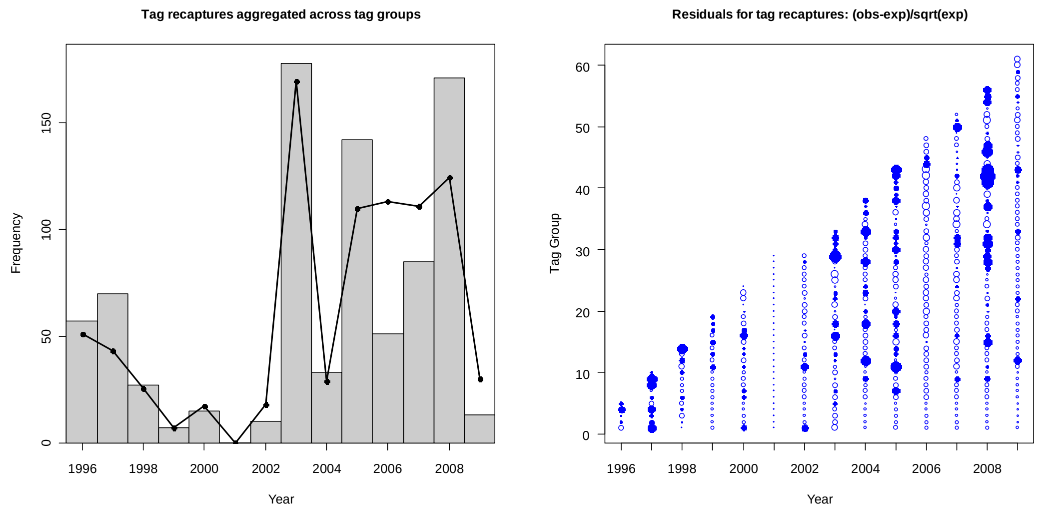

Figure 17 : Summary of the fits to the tag recapture data for Model 1. Left-hand panel shows the summed observed (bars) and expected(line) recaptures over years, and the right-hand panel shows the residuals by tag group and year (blue indicates more recaptures observed than expected).

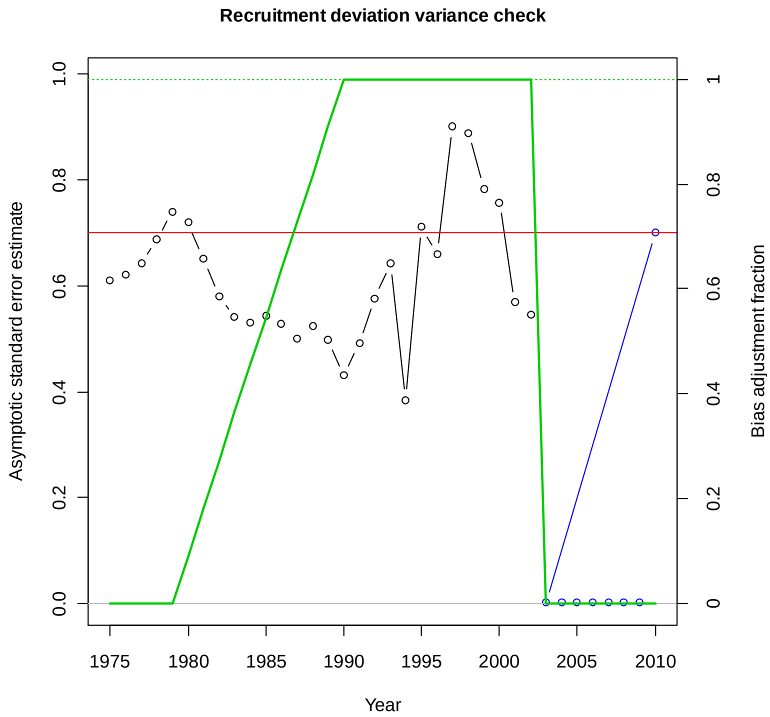

Figure 18 : Asymptotic standard error of estimate for the recruitment deviations for Model 1.