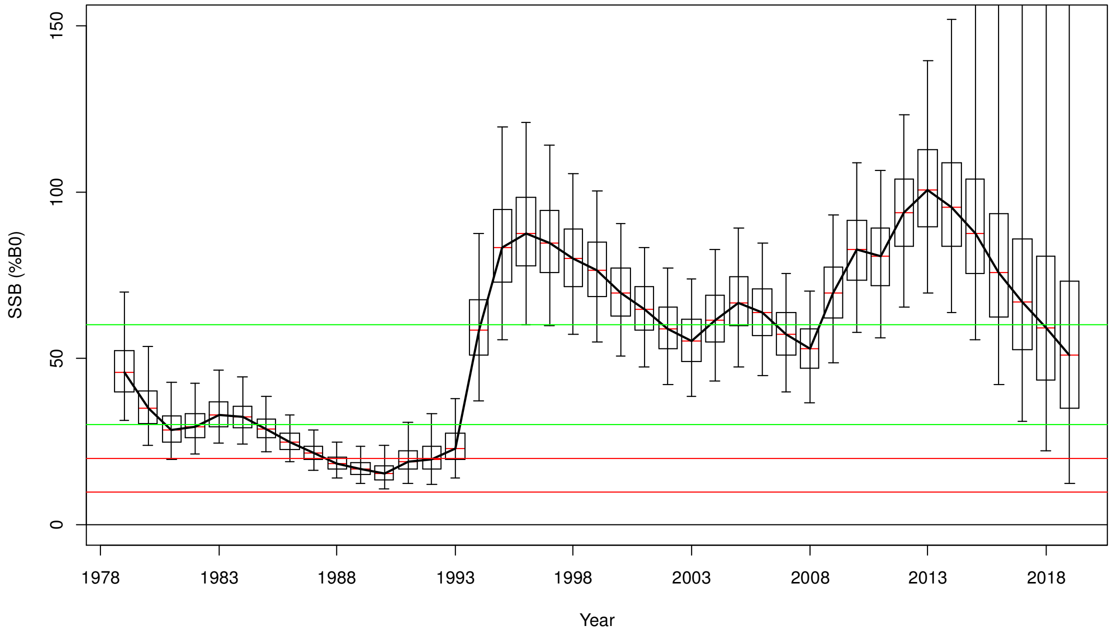

Figure 5: Box and whiskers plot of spawning stock biomass (%B_0) from 1979 to 2019 for the revised stock assessment assuming projected catches at the level of the current TACC (39 200 t). Each box covers 50% of the posterior distribution and the whiskers cover 95% of the distribution. Lines shown at 10%, 20%, 30%, and 60% B_0.

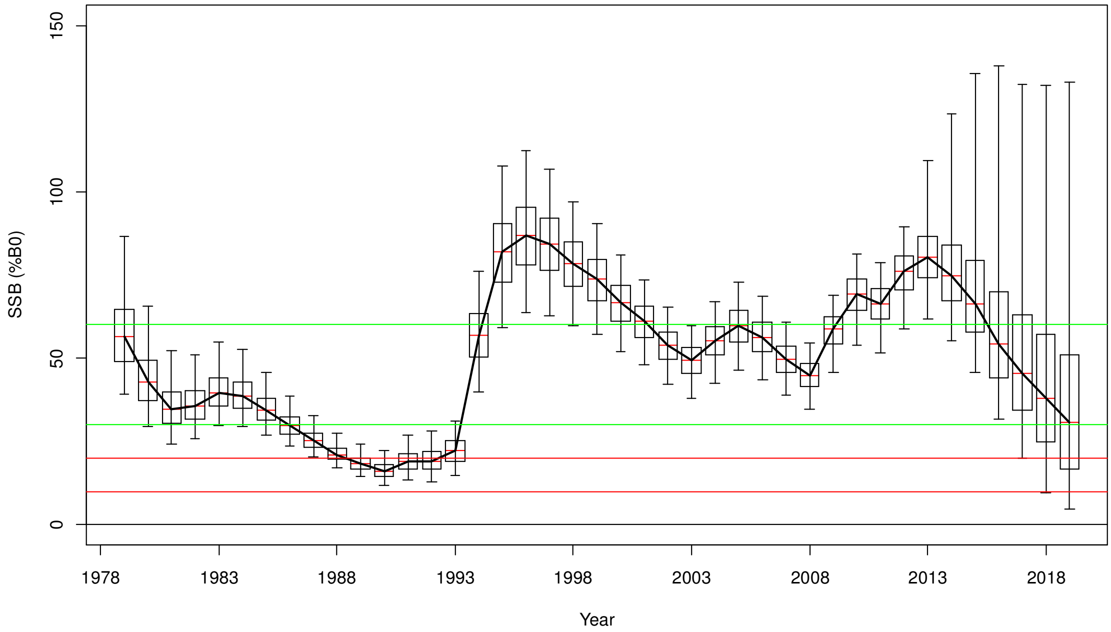

Figure 6: Box and whiskers plot of spawning stock biomass (%B_0) from 1979 to 2019 for when B_0 = 300,000 t is assumed with projected catches at the level of the current TACC (39 200 t). Each box covers 50% of the posterior distribution and the whiskers cover 95% of the distribution. Lines shown at 10%, 20%, 30%, and 60% B_0.

Appendix A: Model equations

Population dynamics

A standard age-structured population dynamics model was used in the simulations: single sex, single area, "instantaneous" catch equation (at the end of the year), with fish numbers tracked by age and maturity state (mature: "*mat*", or immature: "*imm*"). The model was started in deterministic equilibrium with the end-of-year total numbers at age $a = 1, \ldots, 30$ years, $N_{0,a}$:

$$N_{0,a} = R_0 e^{-aM}$$

where R_0 is the number of recruits at age 1 in the virgin population (an arbitrary value of $R_0 = 100$ fish was used). The proportion mature at age a (in the virgin population) was set equal to the median of the posterior distribution from the base MCMC:

Age (years)	**Median**	**95% CI**
2	0.047	0.034–0.064
3	0.60	0.52–0.70
4	0.91	0.83–0.98
5	0.98	0.92–1.00

The annual cycle consisted of ageing, recruitment, maturation, and mortality (a full year of natural mortality followed by instantaneous fishing mortality) in that order. The total number of fish in year y+1 at age a+1 were obtained from the previous end-of-year numbers:

Ageing: a = 1,…,30 years $N_{y+1,a+1} = N_{y,a}$

The recruitment at age 1, in year y+1, was the product of virgin recruitment (R_0), the response from the stock-recruitment relationship ($p_{SR}(B_y)$, where B_y is the mid-season mature biomass in year y (see below)) and the "year class strength" (Y_y) of the cohort:

Recruitment: $N_{y+1,1} = Y_y p_{SR}\left(B_y\right) R_0$

A fixed proportion of immature fish were matured at each age in each year. The fixed maturation ogive was calculated from the proportions mature-at-age in the virgin population:

Maturation: a = 2,…,6 years

$$N_{new,mat,a} = \left(\frac{p_{mat,a} - p_{mat,a-1}}{1 - p_{mat,a-1}}\right) N_{y+1,imm,a}$$

$$N_{y+1,mat,a} = N_{y+1,mat,a} + N_{new,mat,a}$$

$$N_{y+1,imm,a} = N_{y+1,imm,a} - N_{new,mat,a}$$

This formulation ensures that the proportions mature-at-age are in deterministic equilibrium in the virgin population (i.e., do not change when there is no fishing and all YCS are equal to 1).

Mortality was modelled as a full-year of natural mortality followed by an instantaneous non-age-selective fishery on mature fish.

Mortality: $$N_{y,a,end} = (1 - U_y)e^{-M}N_{y,a,begin}$$

where M is natural mortality (independent of age or maturity) and U_y is the exploitation rate in year y. The "N" terms refer to mature or immature numbers at the beginning and end of the year and $U_y = 0$ for immature fish.

The catch was calculated in the usual way:

Catch: $$C_{y,a} = U_y e^{-M}N_{y,a,begin}$$
$$C_y = \sum_a w_a C_{y,a}$$

where w_a is the mean fish weight at age a years (calculated from given von Bertalanffy growth and length-weight relationships which are independent of maturity).

Stock status or depletion in year y, D_y, is defined to be the mid-season mature biomass divided by the mid-season unfished mature biomass: $D_y = B_y/B_{unfished}$. Mid-season occurs when half of the fishing mortality has been applied. The unfished biomass is the average mid-season mature biomass in the virgin population which is almost equal to the deterministic mid-season virgin mature biomass (B_0):

$$B_0 = \sum_a w_a p_{mat,a} R_0 e^{-aM}$$
$$B_{unfished} = cB_0.$$

c is a correction factor which depends on many of the parameters in the population model (particularly the variability and correlation driving the year class strengths, M, and steepness, h, in the stock-recruitment relationship). The correction factors were calculated, as needed, by running the virgin population over 10,000-30,000 years (depending on what was required to make the result independent of the random number seed). The correction factors for the base model ranged from 0.97–1 (over the grid of h and M values used)(Table A1). For the Ricker model, the curvature goes the other way so the correction factors are greater than 1 (Table A2). In the main text, "B_0" is used to denote "$B_{unfished}$" as the distinction is obscure for the general reader.

Table A1: Correction factors required in the base model (Beverton-Holt) to scale deterministic mid-season virgin mature biomass to the average mid-season virgin mature biomass.

	Natural mortality (*M*)							
Steepness (*h*)	**0.18**	**0.20**	**0.22**	**0.24**	**0.26**	**0.28**	**0.30**	**0.32**
0.80	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.97
0.82	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
0.85	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
0.90	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
0.95	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A2: Correction factors required in the Ricker model to scale deterministic mid-season virgin mature biomass to the average mid-season virgin mature biomass.

	Natural mortality (*M*)							
Steepness (*h*)	**0.18**	**0.20**	**0.22**	**0.24**	**0.26**	**0.28**	**0.30**	**0.32**
1.30	1.03	1.03	1.04	1.04	1.04	1.04	1.04	1.05
1.80	1.06	1.06	1.07	1.08	1.08	1.09	1.09	1.10
2.30	1.08	1.09	1.10	1.11	1.11	1.12	1.13	1.14
2.80	1.10	1.11	1.12	1.13	1.14	1.16	1.17	1.18
3.10	1.11	1.12	1.14	1.15	1.16	1.17	1.19	1.20
3.50	1.12	1.14	1.15	1.17	1.18	1.20	1.21	1.23

In the stock-recruitment relationship the uncorrected depletion level (B_y/B_0) was used because that is what gives rise to $B_{unfished}$. In the base model the Beverton-Holt relationship was used:

$$p_{SR}\left(B_y\right) = \frac{B_y/B_0}{\left[1 - \frac{(5h-1)}{4h}\left(1 - B_y/B_0\right)\right]}$$

and in some sensitivities the Ricker relationship was used:

$$p_{SR}\left(B_y\right) = \frac{B_y}{B_0}(5h)^{\frac{5}{4}\left(1-B_y/B_0\right)}\ .$$

The year class strengths, Y_y, were assumed to follow an AR(1) process in log space:

$$Y_y \sim \mathrm{LN}(\mu, \sigma_R),\ Y_y = e^{X_y} \text{ where } X_y = d + \rho X_{y-1} + \epsilon_y,\ \ \epsilon_y \sim \mathrm{N}(0, \sigma^2),\ \text{and } X_0 = 0.$$

It follows that: $\mu = d/(1-\rho)$ and $\sigma_R = \sigma/\mathrm{sqrt}(1-\rho^2)$. The constant d is defined by the requirement that $\mathrm{E}(Y_y) = 1$. There appears to be no analytical solution for d but a good approximation can be found by solving the following equation iteratively:

$$d = \log\left[\frac{1-\rho}{1 - \rho + \rho d + \frac{\rho^2}{2}\left(\frac{\sigma^2}{1+\rho} + \frac{d^2}{1-\rho}\right)}\right] - \frac{\sigma^2}{2}$$

The above equation is derived by noting that

$$E(Y_y) = E(e^{X_y}) = E(e^d e^{\rho X_{y-1}} e^{\epsilon_y}) = e^d E(e^{\rho X_{y-1}}) e^{\frac{\sigma^2}{2}} = 1$$

and approximating $\mathrm{E}(e^{\rho X_{y-1}})$ with a second order Taylor approximation:

$$\mathrm{E}(e^{\rho X_{y-1}}) \cong 1 + \rho\left(\frac{d}{1-\rho}\right) + \frac{\rho^2}{2}\left(\frac{\sigma^2}{1+\rho} + \frac{d^2}{1-\rho}\right)$$

Note that ρ is the correlation coefficient for successive YCS and that when $\rho = 0$ we have $\sigma_R = \sigma$ and the familiar $d = -\sigma^2/2$.

Simulation of assessments

To apply a HCR the current stock status and next year's vulnerable biomass must be estimated. Also, when an acoustic survey is done there must be a boost to the precision of the estimators of stock status and current mid-season spawning biomass. Two mechanisms were used to simulates the estimators.

The first mechanism was to maintain a matrix of *estimated* numbers at age and maturity. This was set up to mimic the accumulation of observations of a cohort as it aged from 2 years (first observation) through to 30 years (as occurs with annual catch-at-age data). The variance of the estimator of the numbers at age a was designed to be proportional to $1/(a-1)$. At the end of each year, the estimated numbers at age $a+1$ was updated via:

$$new\ \widehat{N}_{a+1} = \frac{(a-1)\widehat{N}_{a+1} + N_{a+1}\epsilon}{a}$$

where N_{a+1} is the actual numbers at age $a+1$ (either mature or immature), the "hat" denotes the estimated value and ε is a lognormal random variable with mean = 1 and CV = $\mathrm{CV}_{\mathrm{cohort}}$. The matrix of estimated numbers at age and maturity was passed through the same annual cycle as the actual numbers at age and maturity with all other parameters assumed known so that the unbiased nature of the estimators was maintained. (When biased estimators were used the bias was introduced explicitly by multiplying the unbiased estimators by the given bias.)

The second mechanism was the use of "shrinkage" to adjust the precision of some estimators with a proportion of the true value being used in a weighted average:

$$B_{est} = p\hat{B} + (1-p)B$$

where B_{est} is the more precise version of $\hat{B}$ (both of them being unbiased estimators of B). From the above equation it follows that p can be chosen to give a required improvement in the CV of the estimators:

$$p = \frac{CV(B_{est})}{CV(\hat{B})}$$

This mechanism was used to boost the information contained in the estimators and the estimated numbers-at-age matrix in every year that there was an acoustic survey. In particular, the estimator of mid-season spawning biomass was updated whenever there was a survey using $p_{surv} = 0.73$. This reflects an approximately 9% improvement in CV for each survey (given the target CV of 35% for the estimator of current mid-spawning biomass from the CV of the marginal posterior of B_{13} from the revised assessment). The matrix of estimated numbers at age was also updated whenever there was a survey by scaling the matrix to match the new estimate of mid-spawning season biomass (i.e., it was multiplied by $B_{est}/\hat{B}$).

The shrinkage mechanism was also used to tune the average CVs of the estimators of B_0, B_{mid}, and stock status (to hit targets of 20%, 35%, and 15% respectively). The four parameters used were:

$p_{surv} = 0.73$
$p_{B0} = 0.49$
$p_{ss} = 0.65$
$\text{CV}_{\text{cohort}} = 1.45$

where the "*p*"s are the shrinkage proportions and $\text{CV}_{\text{cohort}}$ is the CV of the lognormal errors used in the generation of estimated numbers-at-age matrix (see above). The tuning was done using the base HCR without any constraints and surveys every 3 years. The average CVs from the run were calculated from the CV of the estimates divided by their true values (and these ratios were checked to make sure they averaged to 1 as expected for unbiased estimators).

The errors were introduced into the estimators via the estimated numbers-at-age matrix. The estimate of next year's vulnerable biomass was calculated from the estimated numbers projected forward to the start of next year's spawning season. The error in B_{vul} was then borrowed for the estimator of B_0 (i.e., B_0 was multiplied by the same proportional error and then the shrinkage mechanism was applied). The B_{mid} estimate came from applying the annual cycle to the estimated numbers at age (in the previous year). Finally, stock status was estimated using the ratio of the B_{mid} and B_0 estimates with shrinkage applied (to the estimator of stock status).

Application of harvest control rules (HCRs)

Each HCR specified an assessment frequency n. In a simulation run, with a given HCR, an assessment was performed in the first year and then every n years after that. In a non-assessment year, the TACC was unchanged. In an assessment year, the provisional TACC was calculated from the HCR using the *estimates* of stock status and vulnerable biomass (see above) and the associated U from the HCR: $\text{TACC}_y = U\hat{B}_{vul,y}$.

The final TACC was determined subject to the constraints. Let m be the minimum change and p_{up} be the up par and p_{down} be the down par (*not* expressed as percentages). Then:

For $\text{TACC}_{\text{old}} /(1 + \text{m}) < \text{TACC}_{\text{provisional}} < (1 + \text{m})\ \text{TACC}_{\text{old}}$ $\quad \text{TACC} = \text{TACC}_{\text{old}}$
and
For $\text{TACC}_{\text{provisional}} > (1 + p_{up}/s)\ \text{TACC}_{\text{old}}$ $\quad \text{TACC} = (1 + p_{up}/s)\ \text{TACC}_{\text{old}}$
and
For $\text{TACC}_{\text{provisional}} < \text{TACC}_{\text{old}}/ (1 + p_{down}/s)$ $\quad \text{TACC} = \text{TACC}_{\text{old}} / (1 + p_{down}/s)$

where s is the estimated stock status.

The total catch was assumed equal to the TACC and in each year it was removed from the stock by calculating the actual fishing mortality required to remove the TACC (i.e., $U_y = \text{TACC}_y/B_{vul,y}$) subject to an 80% maximum exploitation rate.

Appendix B: Revised Campbell Island Rise SBW stock assessment

The most recently reported stock assessment for Campbell Island Rise SBW was to the end of the 2013 calendar year (MPI, 2014). That assessment was not suitable to be used to ground-truth an MSE as it had a fixed $M = 0.2$ and used a faulty prior on the mature acoustic q (MPI, 2014). New assumptions for a prior were developed for the Bounties SBW assessment in 2015 and these assumptions were borrowed to construct a mature acoustic q prior for the revised Campbell Island Rise assessment. Also, M and h were estimated and other minor changes were made. This appendix describes the methods and results for the revised assessment.

Summary of the previous assessment

The assessment is partly documented in the Plenary report (MPI, 2014) and there is another document detailing all SBW input data (Cole et al., 2013). The key points, in terms of model structure were:

- The model started at non-equilibrium in 1979 (early catch history is very uncertain)
- Two-sexes and two areas (home and spawning)
- Ages 2–15 years with a plus-group
- Two time steps with 0.9 natural mortality in the first time step and 0.1 in the second
- The fishery operates in the spawning ground during the second time step
- Fish enter the model at age 2 in the home ground
- Some fish migrate from the home ground to the spawning ground each year (and never return).

The migration is a proxy for maturation. The model structure is equivalent to having age, sex, and maturity in the partition (with just a single area). It was set up with migration instead of maturity to allow for possible annual variation in migration/maturation rates. However, in the base model, migration/maturation rates were constant over time.

The key input data were:

- Wide-area acoustic surveys:
  - 1993-95, 1998, 2000, 2002, 2004, 2006, 2009, 2011, 2013
  - Split into mature biomass and immature biomass
- Catch at age: proportions by age and sex
  - 1979-2013

The key points with regard to estimation were:

- Initial age-structure in 1979 estimated
- Year class strengths from 1977 to 2010 estimated with Haist parameterisation and lognormal priors on the free parameters (mean = 1, CV = 1.3)
- The acoustic indices were relative and so mature and immature acoustic qs were estimated

- An informed prior was used for the mature acoustic *q* (lognormal, mean=0.87, CV=0.3)
- Migration/maturation at age and sex was estimated.

In the base model $M = 0.2$ was assumed based on an early estimate of 0.21 which was rounded down to reflect the imprecision in the estimate (Hanchet 1991). Also, a Beverton-Holt stock-recruit relationship was assumed with a fixed $h = 0.9$. The main changes to the base model were the estimation of *M* and *h* and the use of an updated prior for the mature acoustic *q*.

Summary of the revised assessment model

The CASAL files for the base run in the revised assessment are given in the Annex to this appendix. A summary of the changes made to the previous assessment is given below.

The model structure and the input data were not changed. The only changes related to the estimation methods which were introduced in a step-by-step procedure to see how the changes affected the (MCMC) results.

First, there were two minor changes: fixing the migration proportion at age and sex equal to 1 for ages 6 years and older (this had previously been fixed at 0.5 but the change should make almost no difference as most of the fish have migrated/matured by age 5 years); and using free *q*s in the MCMC (nuisance *q*s had been used which gives an approximation to the correct results obtained by free *q*s – although in this case it may make little difference).

An important change was the use of the Bounties SBW prior for the mature acoustic *q*. The previous (lognormal) prior did not include a factor for tilt-angle distribution and had mean=0.87 and CV=0.3. The tilt-angle factor that was introduced had a range from 0.25–1.0 with a best guess of 0.66 (this was to allow for the unknown tilt-angle distribution of the fish when they were surveyed compared to the near-horizontal distribution of the fish when their target strength was measured). When this factor was included, with minor adjustments to the other factors, the new prior had mean=0.68 and CV=0.77 (from equating the best guess of 0.53 to the median of a lognormal and equating the lower bound of 0.092 to the 0.05 percentile). The changes produce a moderate decrease in the mean and a very large increase in the spread of the prior.

Another minor change was made to use near-uniform priors for the free parameters from which the YCS are derived (under the Haist parameterisation the YCS are the free parameters divided by the mean of the free parameters – which ensures that the estimated YCS average to 1). The previous prior was lognormal with mean=1 and CV=1.3. It is mainly a matter of taste, but as there is no basis for choosing a particular CV for a lognormal prior on the YCS free parameters, it was preferred to use a less informed prior (the near-uniform prior on the free parameters implies a prior on the YCS that is fairly flat between 0 and 2 but also allows much higher values).

The final changes were to estimate M and then h so that the primary uncertainty in the drivers of productivity could be used in the MSE. The prior on M was normal with mean=0.2 and CV=0.15 (which is fairly tight). The prior on h was set to have a mean=0.85 and to eliminate weight below 0.6 to reflect that SBW is *a priori* believed to be resilient (a Beta(10, 1.76) distribution was used). A Ricker informed prior for h was constructed from the Beverton-Holt prior assuming that the distribution of the slopes at the origin were identical for the Beverton-Holt and Ricker relationships (this gave an approximately lognormal prior with mean=2.7, CV=0.5). Also, the MSE operating model was a single-sex model so in the base MCMC non sex-specific parameters were estimated for migration/maturation and natural mortality.

Many additional runs were performed to explore the estimation of M. These included using different means for the prior on M and conditional estimation of M (and the other parameters) for fixed values of B_0.

For all runs, MCMC estimates were obtained by running 3 independent chains starting at a random jump from the MPD estimate. Chains were run out to a minimum of 2,000,000 and a maximum of 15,000,000 samples with every 1000th sample retained. A burn-in of 1000 retained samples was applied. Chains were stopped when convergence appeared adequate on the basis of plots comparing the posterior distributions of the three chains. For some graphing purposes a random subsample of 3000 was taken from the concatenated chains (excluding each burn-in). Medians and 95% CIs were calculated using the full concatenated chains.

Development of the base MCMC for the revised assessment

The base and the "estimate M" models reported in MPI (2014) were re-run without any changes to the CASAL files except for the choice of step-size, proposal distribution, number of chains, and length of chains. The changes were made to obtain more accurate results as only a single chain had been used previously and the results were obtained from a sub-sample of only 1000 posterior samples.

For the base model, the almost-identical runs gave results that were almost identical (Table B1). For the "estimate M" model the results were very close but the repeat run had slightly lower B_0 and slightly higher stock status (Table B1).

Table B1: A comparison of the stock assessment results reported in MPI (2014) and results from almost identical runs. Medians and 95% CIs from the posterior distributions of virgin biomass (B_0) and 2013 spawning biomass (B_{13}) are given for the base and "estimate M" models.

	B_0 (000 t)	**95% CI**	**B_{13} (000 t)**	**95% CI**	**B_{13} (%B_0)**	**95% CI**
Plenary (base)	342	308-391	206	146-285	60	48-74
Repeat (base)	335	300-383	206	146-289	61	48-76
Plenary (est M)	347	298-434	263	168-406	76	54-97
Repeat (est M)	337	289-420	261	170-410	78	56-100

The step-wise changes that were made to the original base model to get a run suitable for ground-truthing the MSE produced increasing larger estimates of B_{13} and stock status (Table B2). Individually the use of the new prior on the mature acoustic q and the estimation of M only produced small to moderate increases to estimated stock status (65% and 78% B_0 respectively compared to 60% B_0). However, when both changes were present, estimated stock status was much higher at 94% B_0 (Table B2).

Table B2: A comparison of the stock assessment results reported in MPI (2014) and results from this study. Medians and 95% CIs from the posterior distributions of virgin biomass (B_0) and 2013 spawning biomass (B_{13}) are given for the original base model and runs with a succession of changes. (Changes were cumulative as indicated by "+"; "n. unf. prior" denotes a nearly-uniform prior on the free parameters from which the YCS are derived.)

	B_0 (000 t)	95% CI	B_{13} (000 t)	95% CI	B_{13} (% B_0)	95% CI
Plenary (base)	342	308-391	206	146-285	60	48-74
Repeat (base)	335	300-383	206	146-289	61	48-76
+ New q prior	345	305-402	222	155-317	65	50-80
+ YCS n. unf. prior	356	312-423	256	180-371	72	57-88
+ est M	393	316-677	368	212-818	94	65-124
+ est h	374	303-606	351	206-723	94	65-123
+ est h (Ricker)	228	168-447	248	154-535	109	87-129

The final change was to estimate non sex-specific migration/maturation parameters for use in the single-sex operating model. There are small differences between the estimates by sex with males maturing earlier but such differences would not be expected to have any effect on the performance of HCRs. The use of a single-sex maturation/migration pattern caused only minor changes in the estimates of B_0 and B_{13} (Table B3).

Table B3: A comparison of the results for the two-sex and single-sex migration parameterisations. Medians and 95% CIs from the posterior distributions of virgin biomass (B_0) and 2013 spawning biomass (B_{13}) are given for the Beverton-Holt (BH) and Ricker runs.

	B_0 (000 t)	95% CI	B_{13} (000 t)	95% CI	B_{13} (%B_0)	95% CI
Est *M, h* (BH, 2-sex)	374	303-606	351	206-723	94	65-123
Est *M, h* (BH, 1-sex)	390	308-689	378	216-842	97	68-126
Est *M, h* (Ricker, 2-sex)	228	168-447	248	154-535	109	87-129
Est *M, h* (Ricker, 1-sex)	236	171-563	259	159-692	109	88-130

The Beverton-Holt model with the full suite of changes, including the single-sex parameterisation for M and migration/maturity, is the base model for the revised assessment.

Revised assessment: base MCMC model diagnostics

A comprehensive check of the diagnostics for the revised base model was made to ensure that it was an acceptable assessment that could be used to ground-truth the MSE.

The three chains delivered almost identical marginal posterior distributions for B_0, B_{13}, stock status, M, and h (Figures B1-B5).

The MCMC "fit" to the mature acoustic indices was good with the marginal posterior distributions following the general trend of the indices (Figure B6). The normalised residuals were also adequate showing that the mature indices had an appropriate data weighting (Figure B7). The same cannot be said for the immature acoustic indices. Although the "fit" was not too bad (Figure B8) it was clear from the normalised residuals that the indices were given too much weight (Figure B9). The data weights (CVs and sample sizes) from the original base model were used in all the runs. In the next assessment it would be best to down-weight the immature acoustic indices (but this is very unlikely to affect the results of the assessment as they are only a weak relative index for immature fish).

The Pearson residuals for the catch-at-age data show no patterns across years (Figure B10). However, there is the expected pattern in residuals by sex at ages 2 and 3 years (Figures B11 and B12). This is caused by males maturing in higher proportions than females at ages 2 and 3 years.

Revised assessment: base MCMC model results

The marginal posterior distribution for the mature acoustic q is shifted and contracted to the left of the prior distribution (Figure B13). It has a mode at 0.25 with very little weight above 0.5. This suggests that the tilt-averaged target strength in the spawning aggregations is much lower than the estimated target strength from the AOS recordings (fish herded by the trawl net). The marginal posterior distribution for the immature acoustic q is much tighter than its uniform prior (Figure B14). It has a mode at 0.15 with very little weight above 0.4.

The marginal posterior distribution for M is shifted to the right of the prior but has a similar spread (Figure B15). The median and 95% CI are 0.25 and 0.19–0.31. For Beverton-Holt h, the posterior is shifted to the right of the prior and is much tighter with little weight below 0.8 (Figure B16). The median and 95% CI are 0.95 and 0.84–0.99.

The cumulative proportions migrating/maturing at age are tightly defined with median estimates of 0.047, 0.60, 0.91, and 0.98 at ages 2–5 years respectively (Figure B17). The YCS shows the same pattern as the original assessment with very strong cohorts estimated for 1991, 2006, and 2009 (Figure B18). The SSB trajectory also shows the same pattern as the original assessment except that it finishes at a much higher level (~ 100% B_0 rather than ~60% B_0)(Figure B19).

Estimation of M in the model is problematic because the estimates are dependent on the prior used (Table B4). As the mean of the prior on M is increased so are the estimates of M and of B_0. The problem with estimating M within the model is that information on M comes from the right-hand limbs of the catch-at-age data. These provide information for $Z = F + M$ and because B_0 is uncertain then F is uncertain and the estimation of M and B_0 is confounded.

However, estimation of M externally to the model is an even worse option as allowances cannot be made for catch, the maturity ogive, and highly variable YCS. As an example, consider the use of catch curves to estimate Z from the earliest known part of the fishery (Figure B20). From 1979 to 1984 one would have to estimate Z (and hence M) at something less than 0.1; while from 1985 to 1989 an estimate of M at about 0.2 would be the likely choice. Of course, these estimates of Z are just driven by the variation in recruitment rather than fishing and natural mortality. This becomes obvious when $Z \sim 1.7$ when the very strong 1991 cohort is 6 years old and produces a very steep slope in the right-hand limb of the catch curve (see Figure B20 for the Z estimate).

From a pragmatic viewpoint, the mean of the prior on M cannot be larger than about 0.2 because at higher values the estimates of the mature acoustic q become untenable (Table B4). Essentially as M becomes large so does B_0 and hence SSB biomass is very large during the period of the acoustics surveys and the q becomes far too small (e.g., Figure B21).

Table B4: Population parameter estimates for the base MCMC (N(20)) and variations with alternative priors on *M* (normal with the given mean and a CV of 15%, and uniform from *M*=0.05 to 0.5). Medians and 95% CIs are given for virgin biomass (B_0), natural mortality (*M*), stock-recruitment steepness (*h*), recruitment variability (Rsd), recruitment correlation (Rho), and the mature acoustics *q* (Aco. *q*).

***M* prior (%)**	**B_0 (000 t)**		***M* (%)**		***h* (%)**		**Rsd (%)**		**Rho (%)**		**Aco. *q* (%)**	
N(15)	350	310-420	18	14-22	97	88-100	110	100-130	19	5-33	40	27-55
N(20)	390	310-690	25	19-31	95	84-99	120	110-130	25	9-40	24	11-41
N(25)	590	360-810	31	25-35	94	80-99	120	110-130	27	11-41	12	9-27
N(30)	660	410-820	33	28-37	93	79-99	120	110-130	26	9-40	11	9-20
N(35)	680	450-830	34	30-39	93	78-99	120	110-130	24	8-39	10	9-17
Unf. (5, 50)	700	450-840	35	29-39	93	78-99	120	100-130	23	7-39	10	9-17

The question of whether a mean of something less than 0.2 should be used for the prior is answered by a series of MCMC runs for given values of B_0. The confounding of B_0 and *M* is of course eliminated when B_0 is known. In this case a uniform prior can be used for *M* and the data contain excellent information on *M* (for given B_0). The results show that the lowest estimates of *M* are obtained for B_0 ~ 300,000 t (Figure B21, median and 95% CI: 0.25, 0.2–0.3). For B_0 values lower than 300,000 t the estimates of *M* increase because higher productivity is needed to support the historical catches (since B_0 is so low). When a prior on *M* with mean 0.15 is used the posterior distribution has a median of 0.18 and 95% CI of 0.14–0.22 (Table B4). This is inconsistent with the range on *M* from the conditional estimates (~ 0.18–0.4). It is not a pure Bayesian approach, but of the priors used for *M* only N(mean=0.2) gives results that are consistent with the plausible range of *M* ~ 0.18–0.4 and doesn't estimate the mature acoustics *q* to be too low.

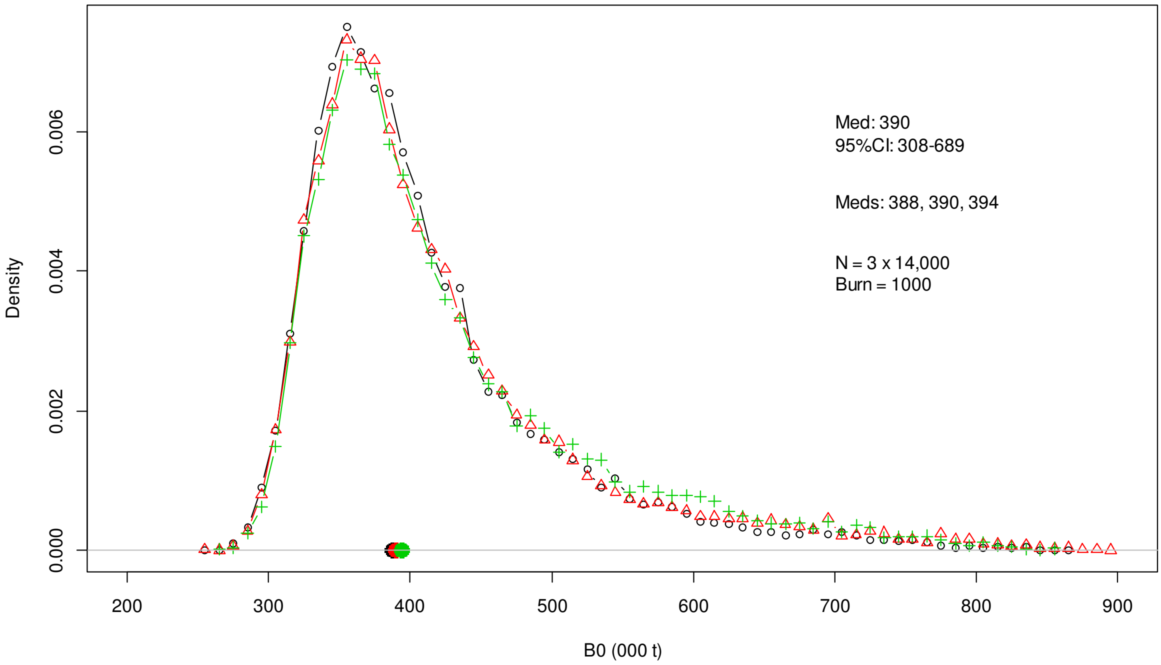

Figure B1: The marginal posterior distributions of B_0 for the three independent chains used for the revised base model. The median and 95% CI are given for the combined chains after burn-in together with the individual medians (000 t).

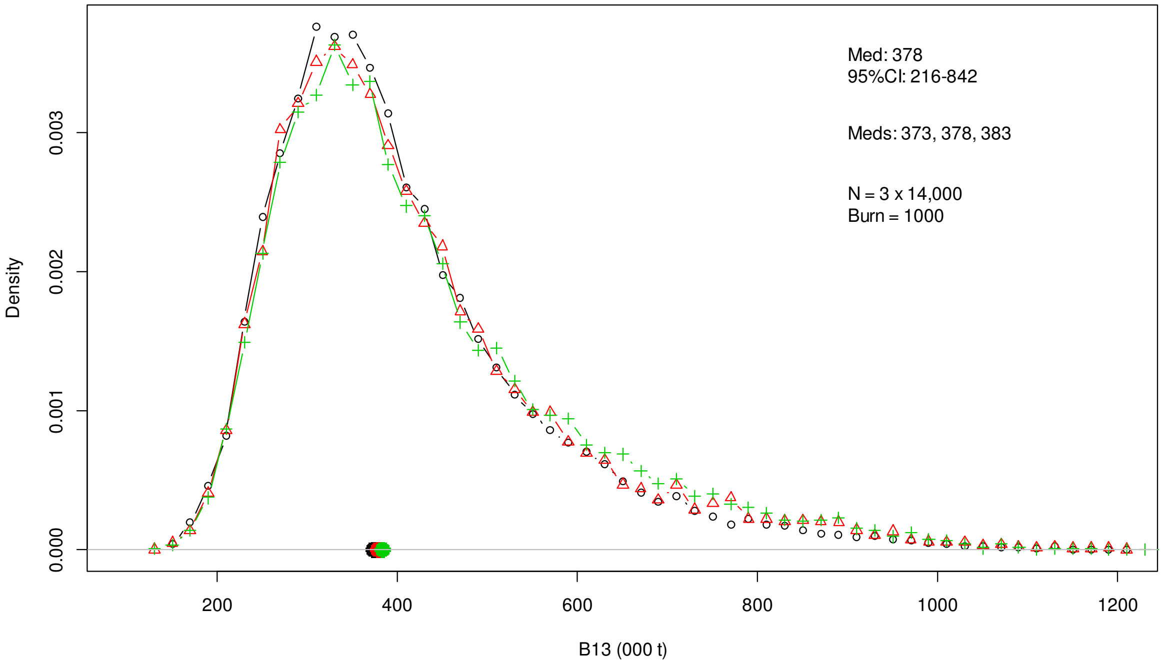

Figure B2: The marginal posterior distributions of B_{13} for the three independent chains used for the revised base model. The median and 95% CI are given for the combined chains after burn-in together with the individual medians (000 t).

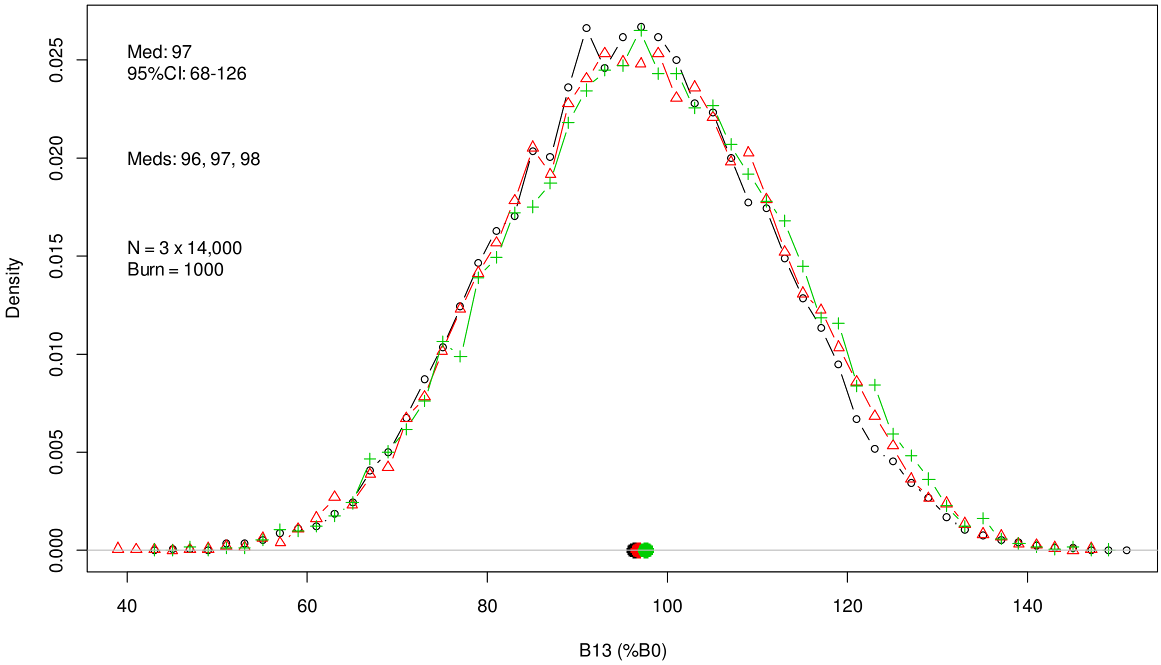

Figure B3: The marginal posterior distributions of stock status (B_{13}/B_0) for the three independent chains used for the revised base model. The median and 95% CI are given for the combined chains after burn-in together with the individual medians (%B_0).

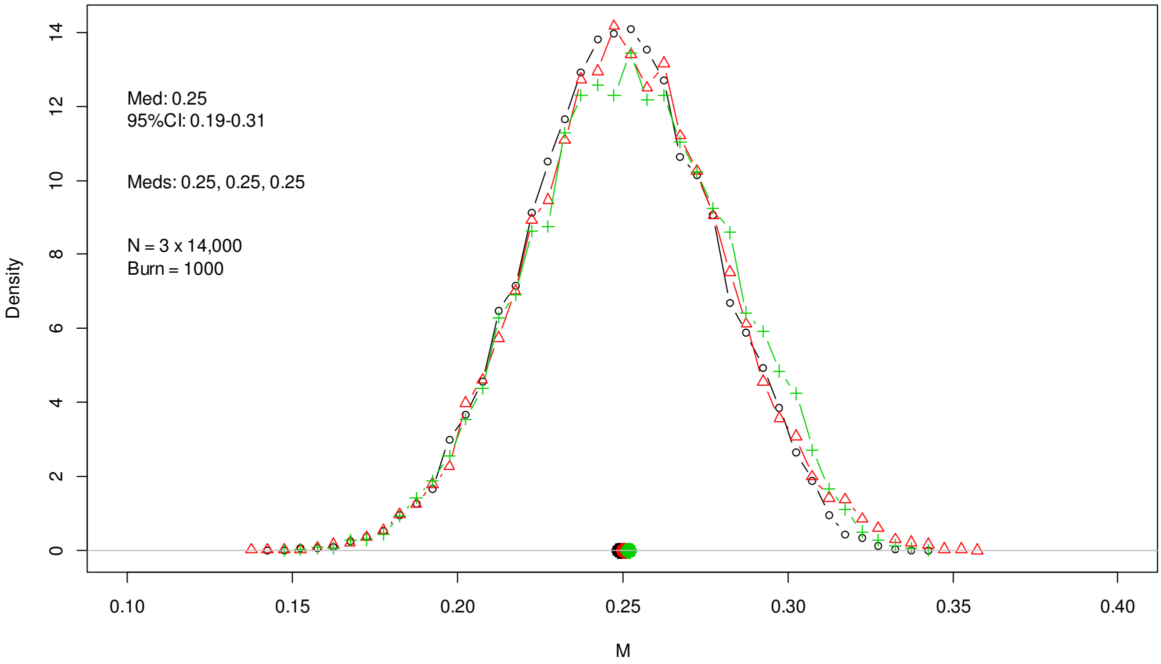

Figure B4: The marginal posterior distributions of M for the three independent chains used for the revised base model. The median and 95% CI are given for the combined chains after burn-in together with the individual medians.

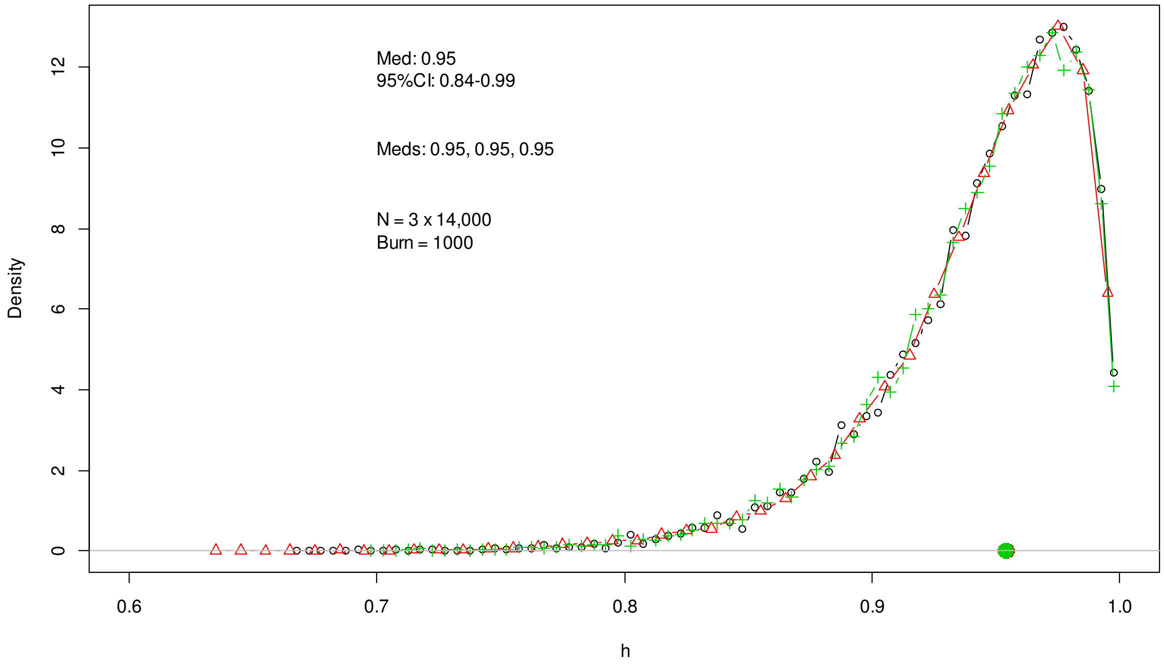

Figure B5: The marginal posterior distributions of h for the three independent chains used for the revised base model. The median and 95% CI are given for the combined chains after burn-in together with the individual medians.

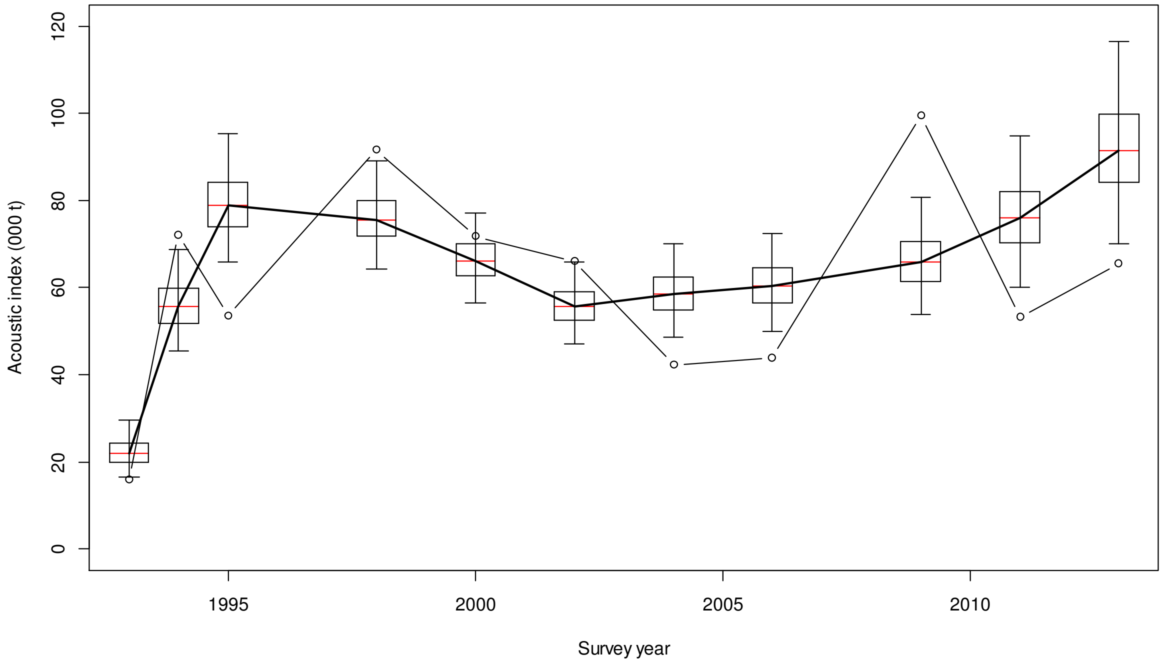

Figure B6: The MCMC "fit" to the mature acoustic indices. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers) for the marginal posterior distribution of each predicted average index. The observed indices are the open circles.

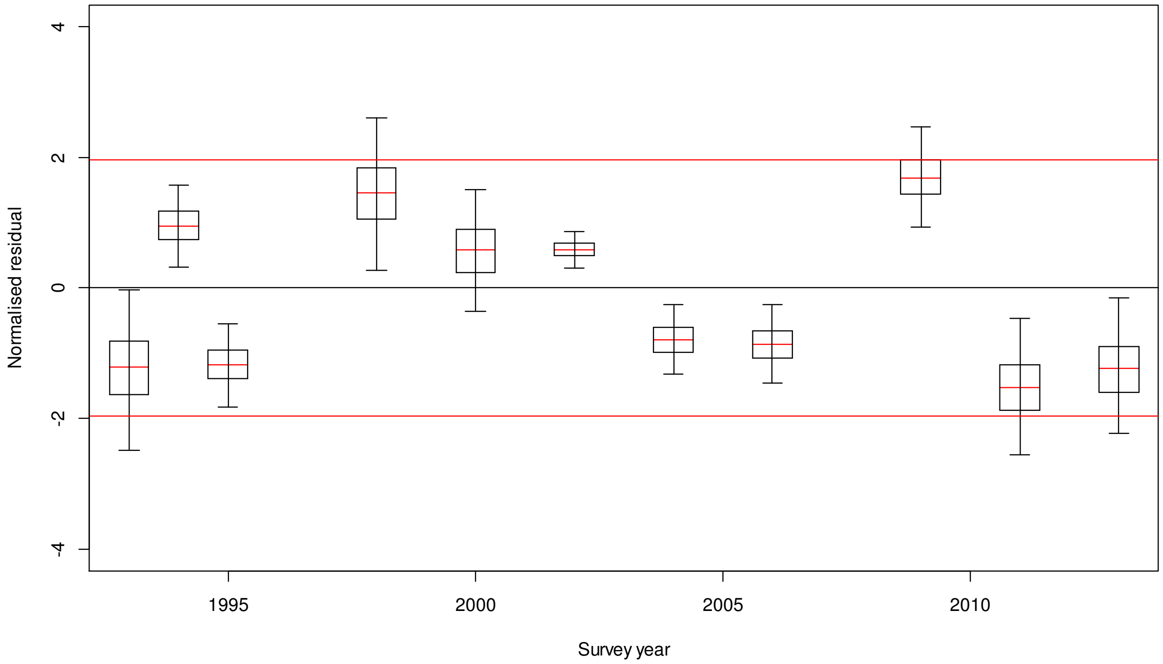

Figure B7: The normalised residuals for the mature acoustic indices. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers). The red horizontal lines are at ± 1.96 which represents 95% of a standard normal distribution.

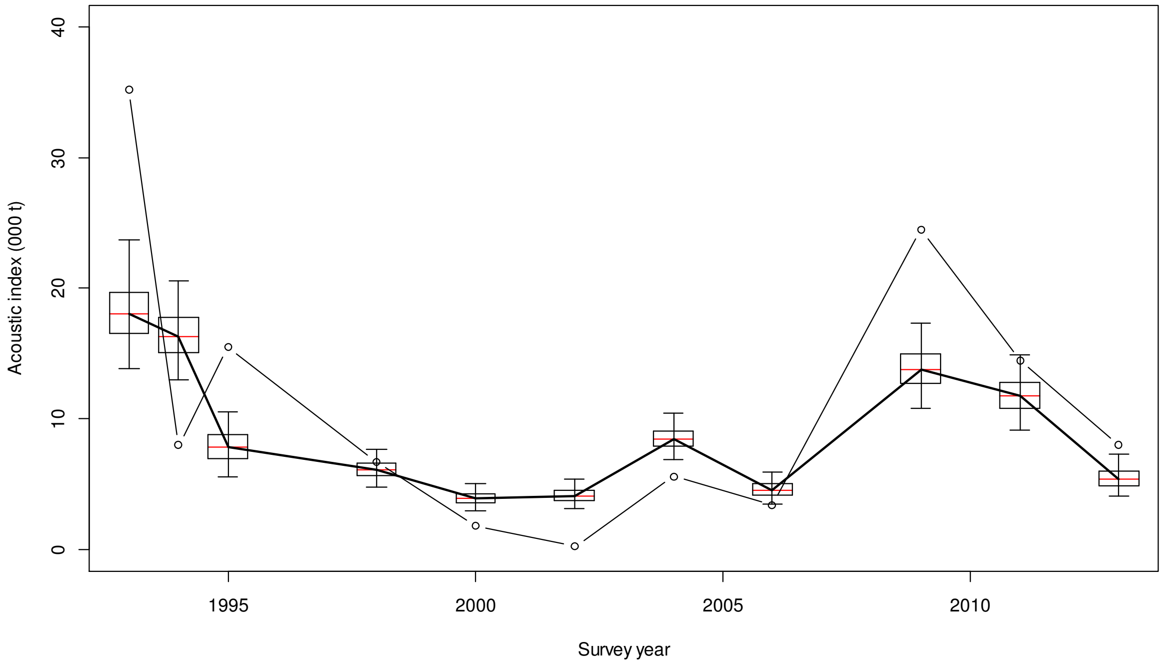

Figure B8: The MCMC "fit" to the immature acoustic indices. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers) for the marginal posterior distribution of each predicted average index. The observed indices are the open circles.

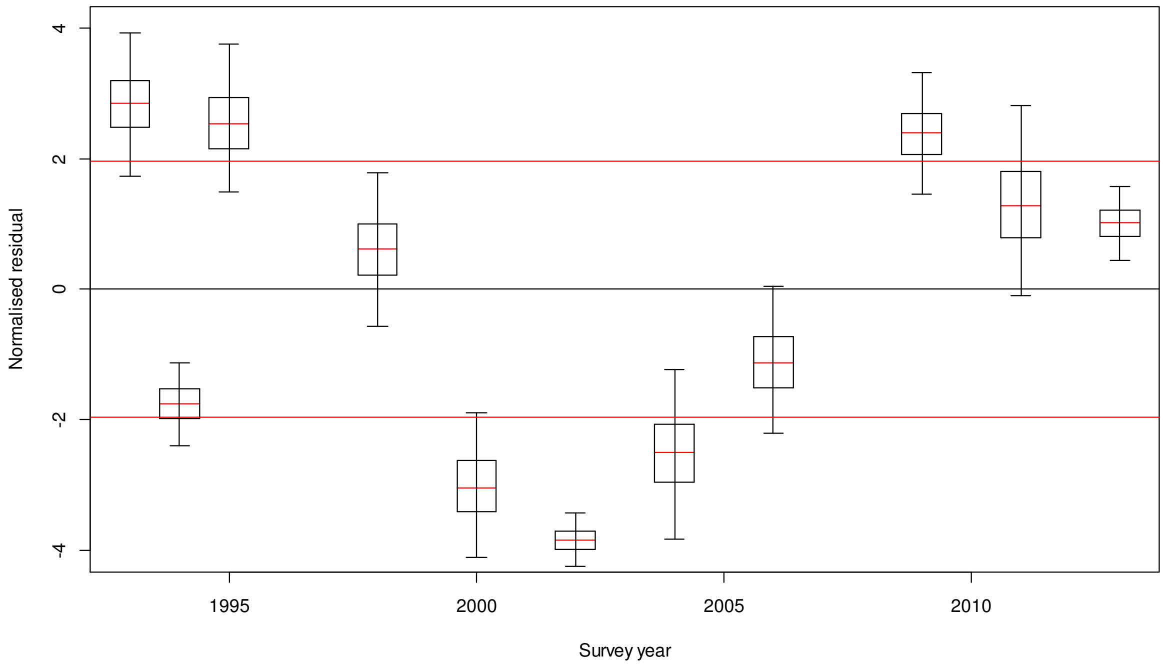

Figure B9: The normalised residuals for the immature acoustic indices. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers). The red horizontal lines are at ± 1.96 which represents 95% of a standard normal distribution.

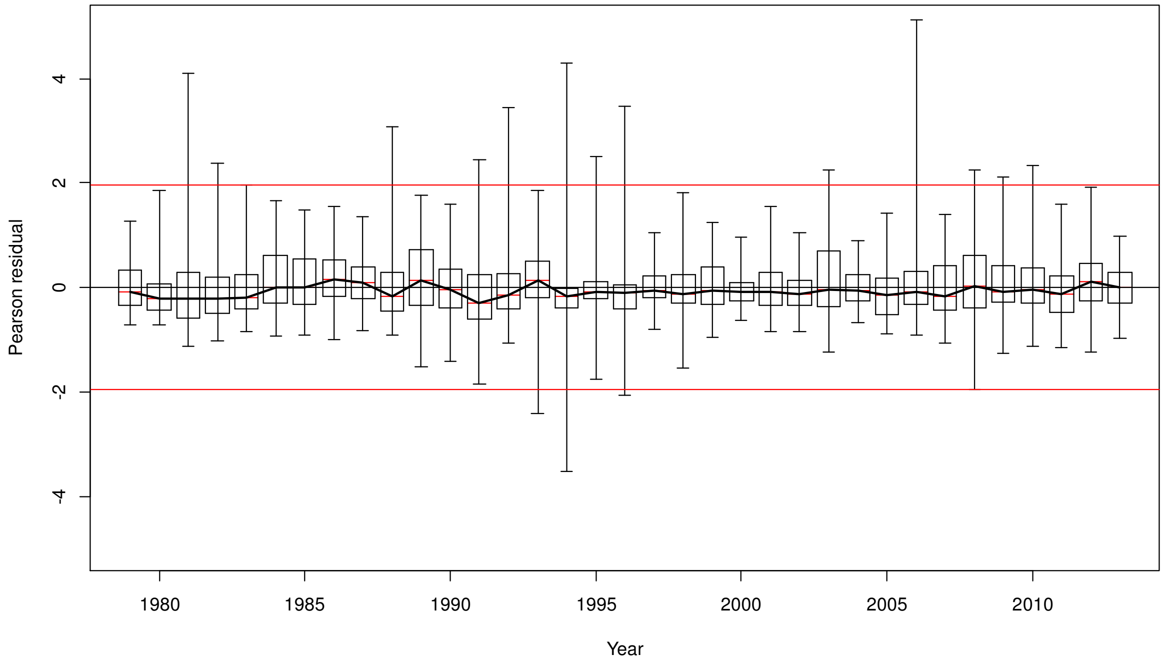

Figure B10: The Pearson residuals for the catch-at-age data (over both sexes) by year. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers). The red horizontal lines are at ± 1.96 which represents 95% of a standard normal distribution.

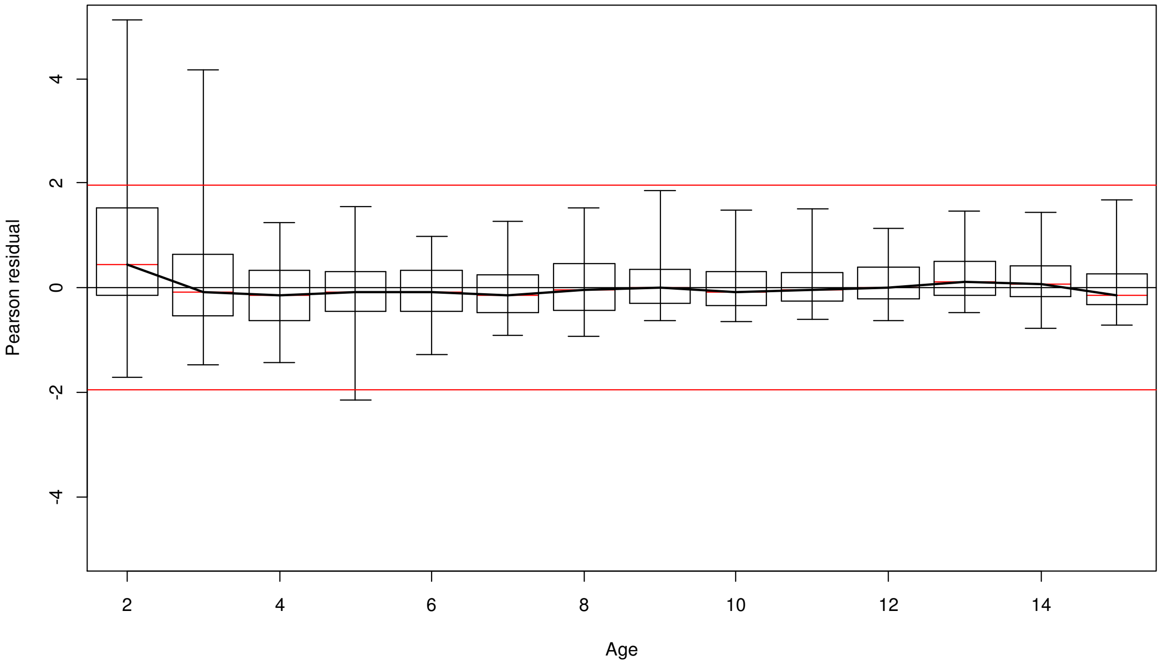

Figure B11: The Pearson residuals for the male catch-at-age data by age. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers). The red horizontal lines are at ± 1.96 which represents 95% of a standard normal distribution.

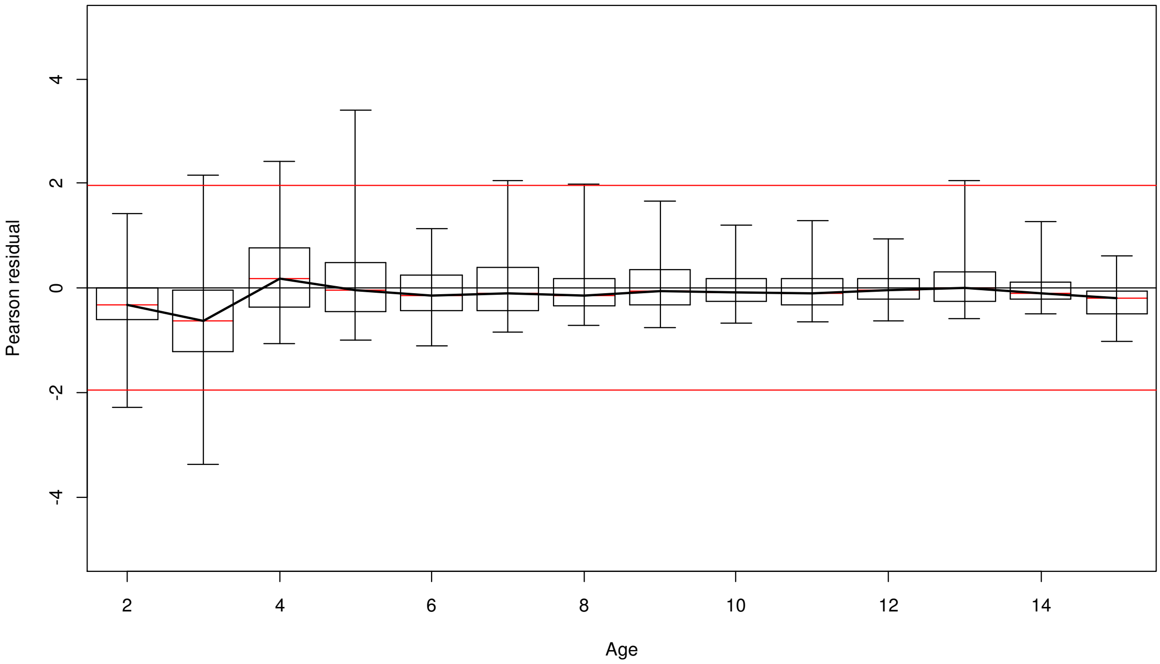

Figure B12: The Pearson residuals for the female catch-at-age data by age. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers). The red horizontal lines are at ± 1.96 which represents 95% of a standard normal distribution.

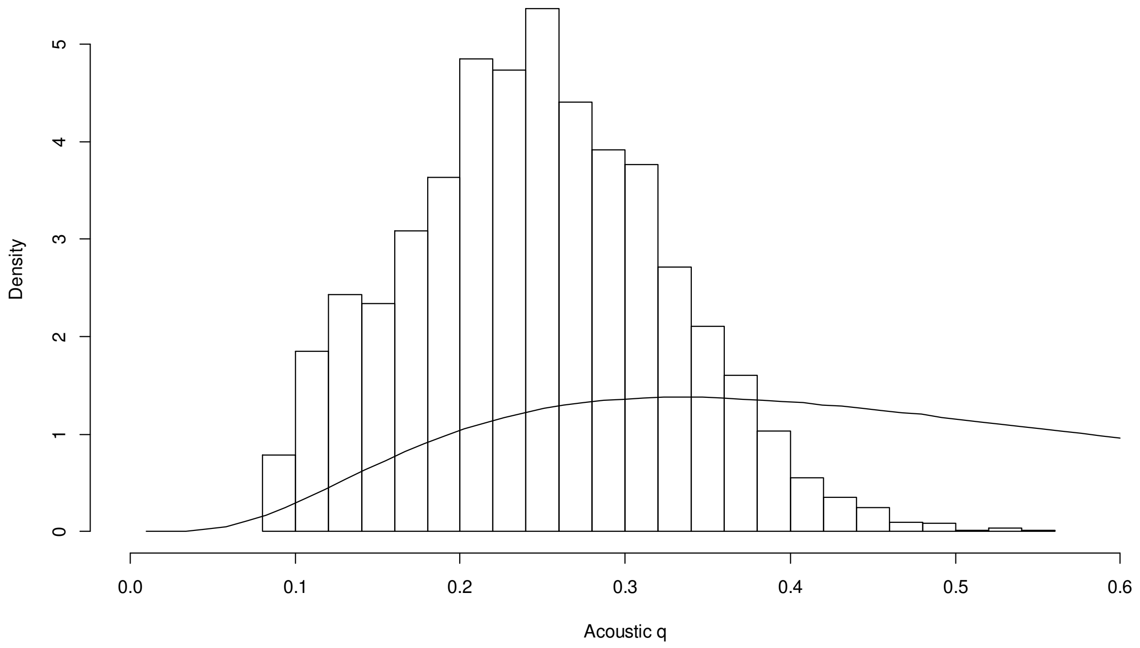

Figure B13: The marginal posterior distribution (histogram) and prior (smooth line) for the mature acoustic q.

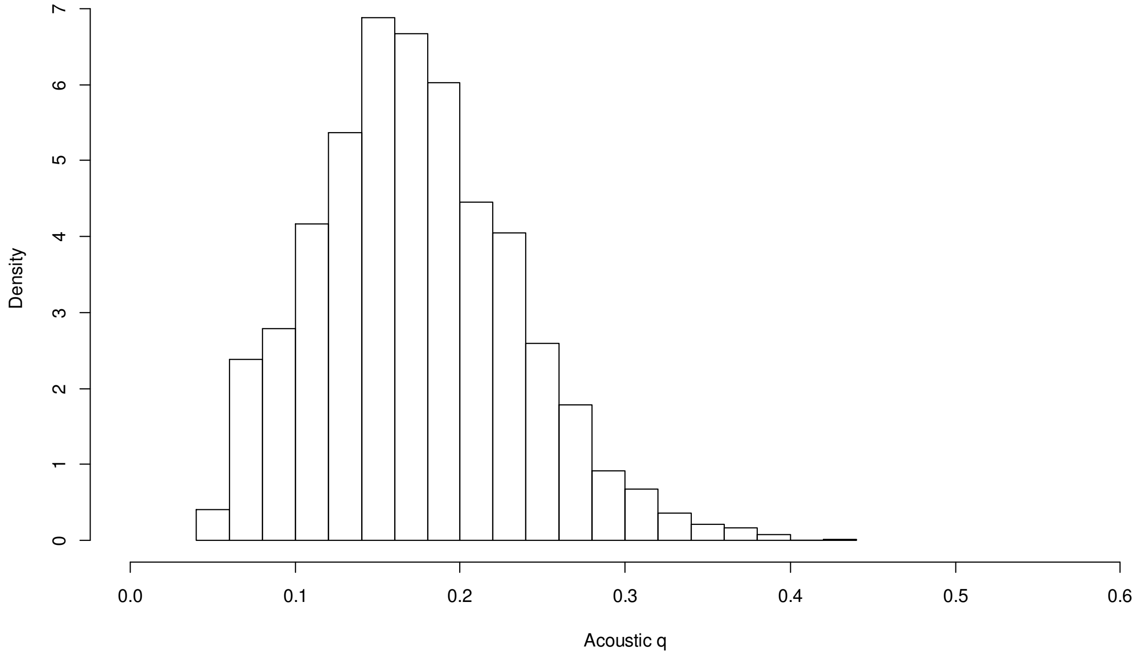

Figure B14: The marginal posterior distribution for the immature acoustic q. The prior was uniform.

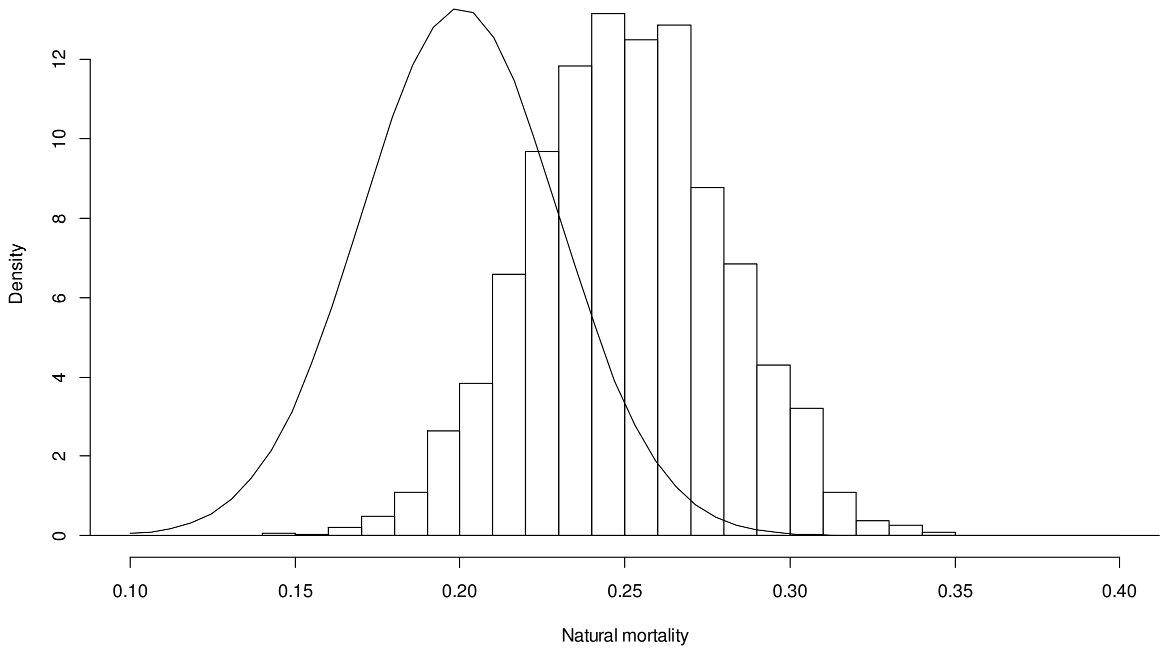

Figure B15: The marginal posterior distribution (histogram) and prior (smooth line) for M.

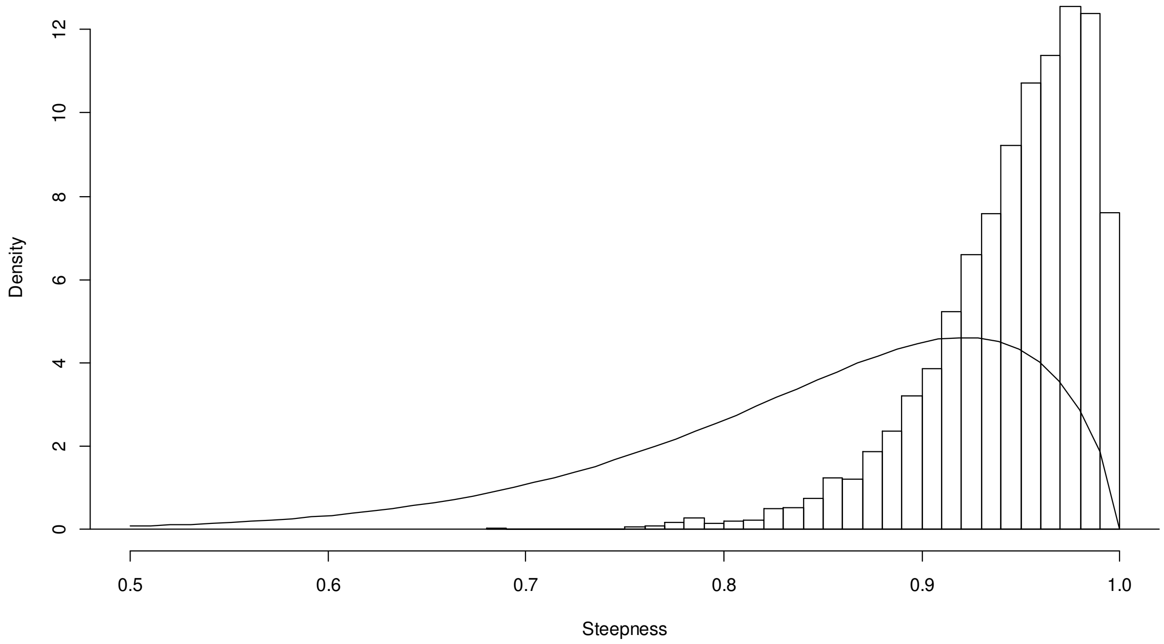

Figure B16: The marginal posterior distribution (histogram) and prior (smooth line) for h.

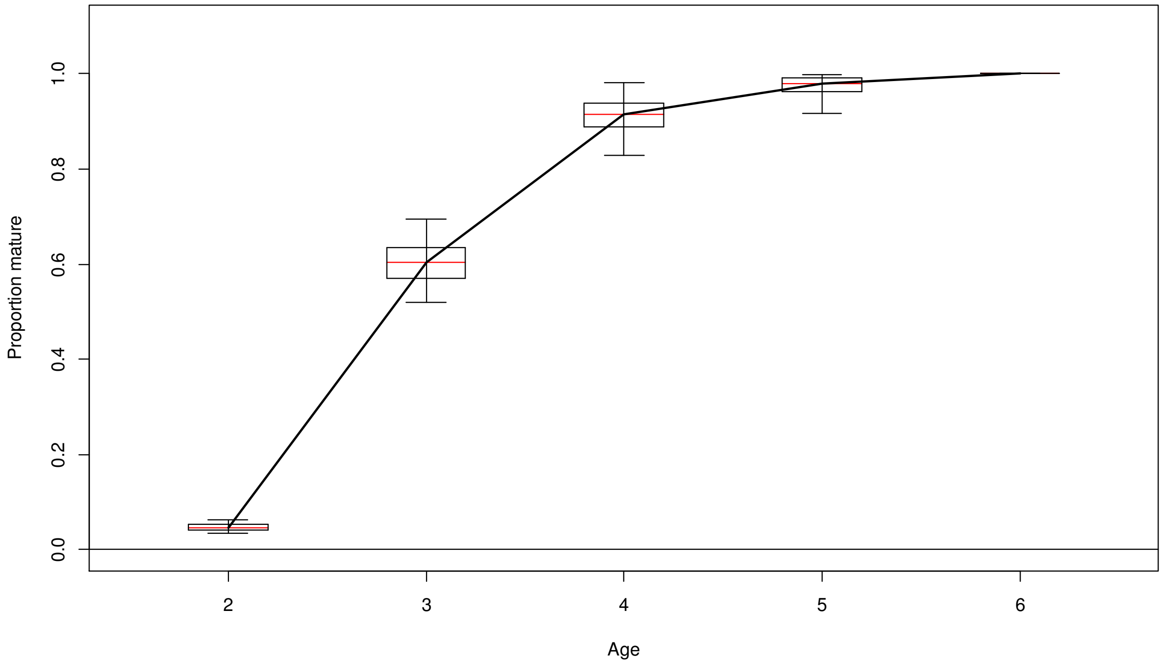

Figure B17: The MCMC estimates of the cumulative migration (maturation) proportion at age. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers) for the marginal posterior distribution. The proportion was fixed at 1 for ages 6 years and older.

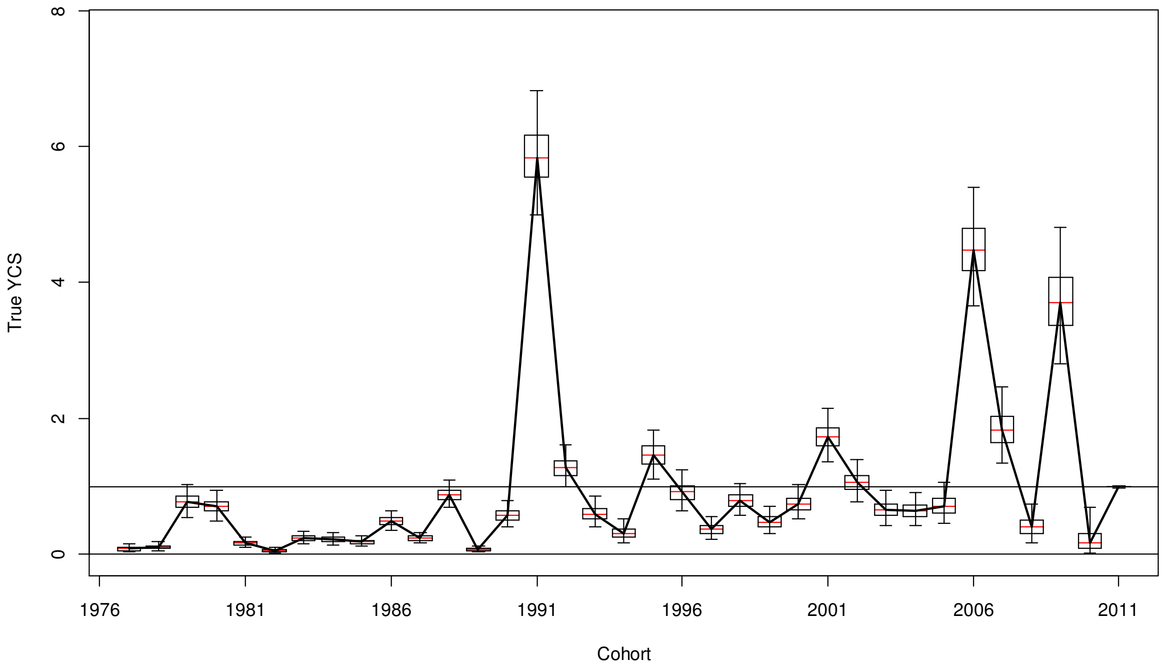

Figure B18: The MCMC estimates of the “true” YCS (R_y/R_0) for cohorts spawned in 1977 to 2010 inclusive. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers) for the marginal posterior distribution.

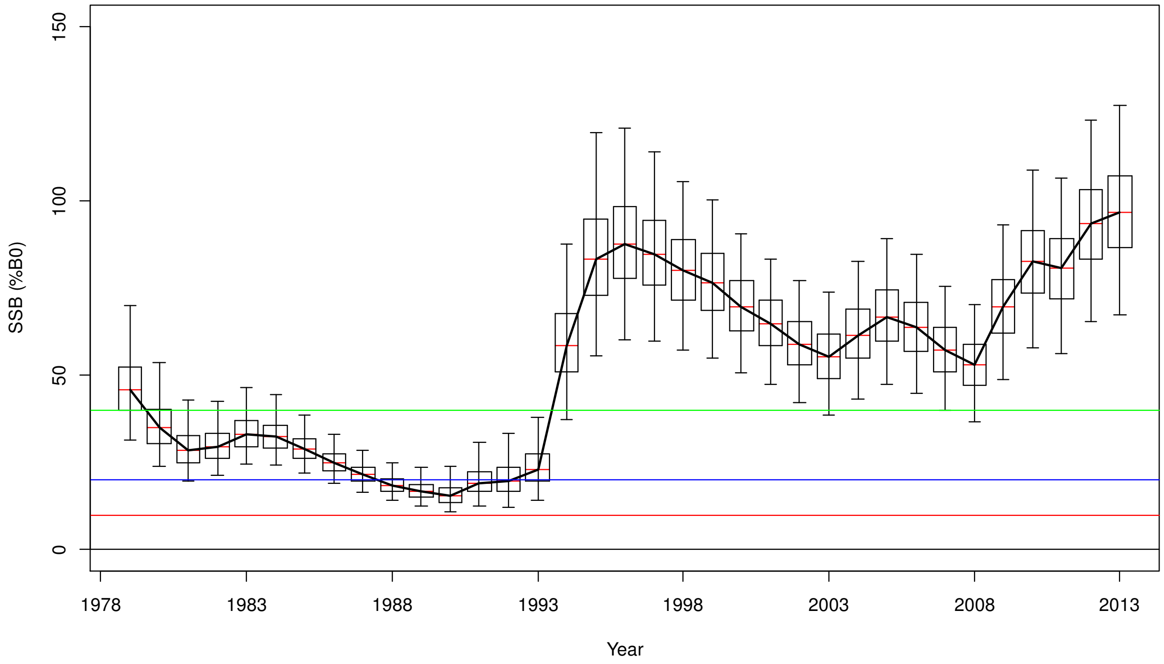

Figure B19: The MCMC estimate of the stock status trajectory (B_y/B_0). Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers) for the marginal posterior distribution. The red, blue, and green horizontal lines are at 10%, 20%, and 40% B_0 respectively.

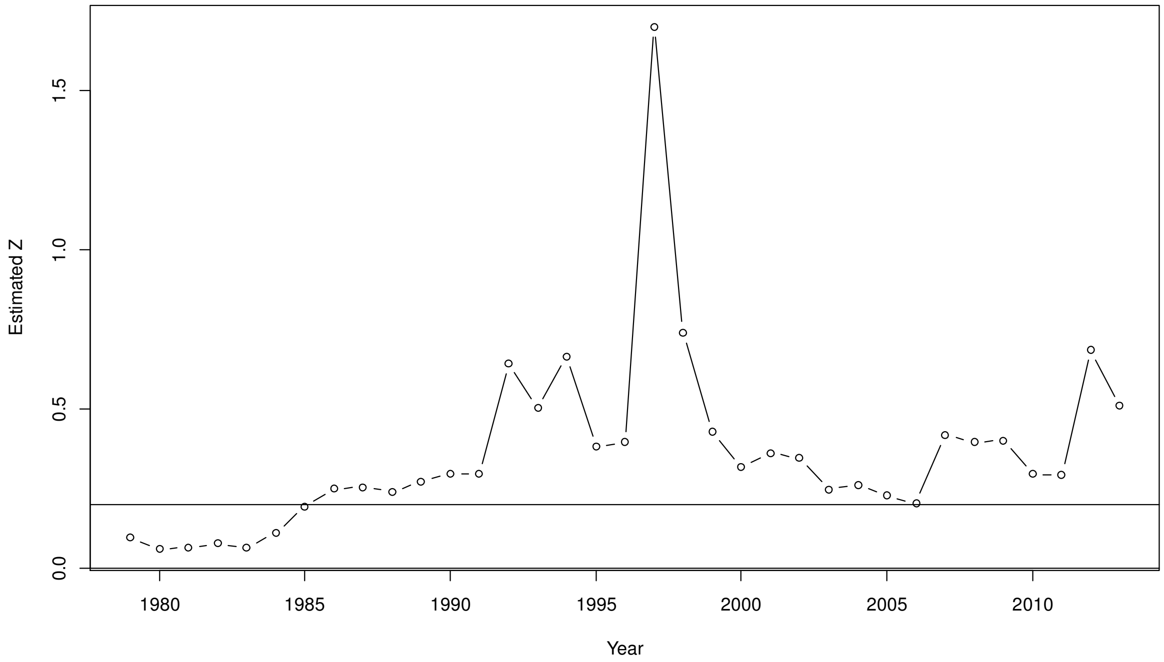

Figure B20: Maximum likelihood estimates of Z from the annual catch-at-age data assuming full recruitment at 6 years of age. The horizontal line is at 0.2.

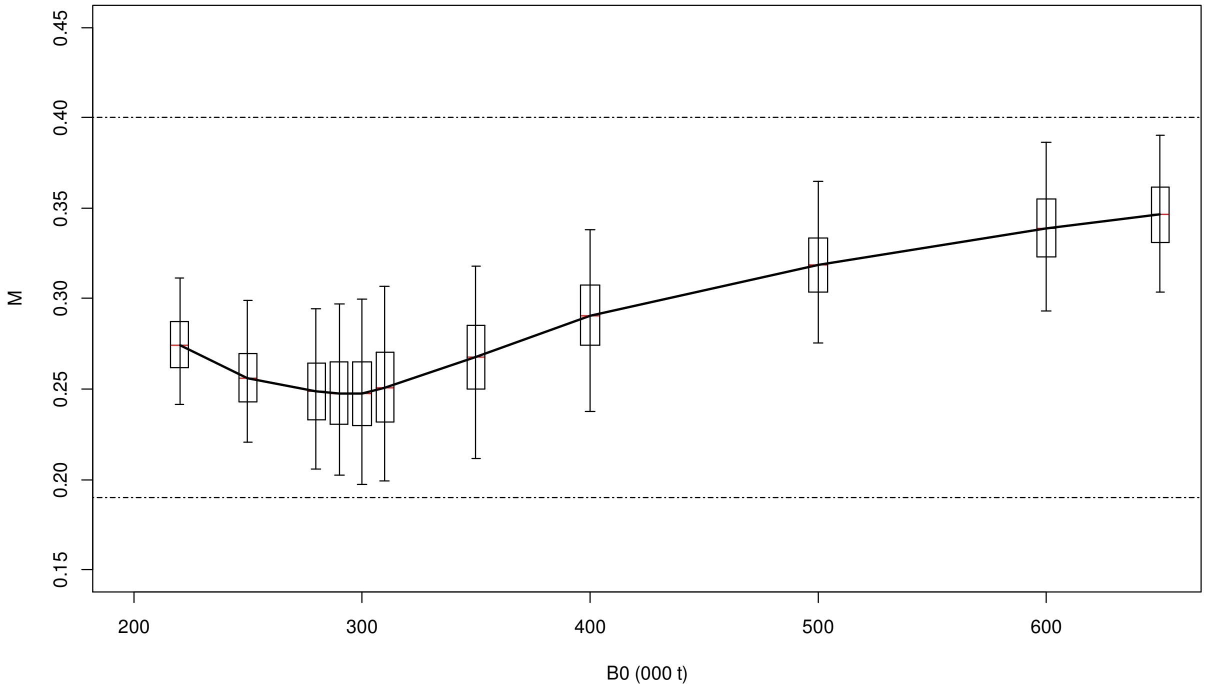

Figure B21: The MCMC estimates of M when B_0 is fixed and a uniform prior is used for M. Each box and whiskers plot gives the median (red line), middle 50% (box) and 95% CI (whiskers) for the marginal posterior distribution. Horizontal dashed lines are at 0.18 and 0.4.

Annex to Appendix B: The CASAL files for the base MCMC

Population.csl

```
# Note all years are calendar years, not fishing years, because
fishery happens in August

@initialization
B0 60000
#Binitial 1e5
Cinitial_male allvalues   5e7 5e7 7e6 6e6 5e6 4e6 3e6 2e6 1e6 1e6
1e1 1e1 1e1 1e1
Cinitial_female allvalues 5e7 5e7 7e6 6e6 5e6 4e6 3e6 2e6 1e6 1e6
1e1 1e1 1e1 1e1
@size_based False
@min_age 2
@max_age 15
@plus_group True
@sex_partition True
@mature_partition False
@n_areas 2
@n_stocks 1
@area_names spawn nonspawn

@initial 1979
@current 2013
@final 2019

@annual_cycle
time_steps 2
recruitment_time 2
maturation_times 2
n_migrations 1
migration_times 2
migrate_from nonspawn
migrate_to   spawn
migration_names toSpawn
spawning_areas spawn
recruitment_areas nonspawn
spawning_time 2
spawning_part_mort 0.5
spawning_ps 1.0
ageing_time 2
M_props 0.9 0.1
baranov False
fishery_names Trawl
fishery_times     2
fishery_areas spawn
growth_props 0 0
spawning_use_total_B True

@y_enter 2
@standardise_YCS True
@recruitment
```

```
YCS_years 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
YCS          1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    1
SR BH
steepness 0.9
p_male 0.5
sigma_r 1.0
first_free 1977
last_free 2010
year_range 1977 2010

@randomisation_method lognormal
@first_random_year 2010

@natural_mortality
all 0.20

@maturity_props
all constant 1

@migration toSpawn
migrators all
rates_all   allvalues_bounded 2 6  0.15 0.7 0.95 0.50 1

@fishery Trawl
years    1979  1980  1981 1982 1983  1984  1985 1986  1987  1988
1989  1990  1991  1992  1993 1994  1995  1996  1997  1998  1999
2000  2001  2002  2003  2004  2005  2006  2007  2008  2009  2010
2011  2012  2013
catches 25305 12828 5989 7915 12803 10777 7490 15252 12804 17422
26611 16542 21314 14208 9316 11668 10436 16504 18923 27164 27205
18052 28232 33445 23718 19799 26190 19763 20996 20483 19040 20224
30982 21321 28607
U_max 0.8
selectivity TrawlSel

@selectivity_names TrawlSel TangaroaMatureSel TangaroaImmatureSel
@selectivity TrawlSel
all constant 1
@selectivity TangaroaMatureSel
all constant 1
@selectivity TangaroaImmatureSel
all logistic 2 3

@size_at_age_type  data
@size_at_age_years 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
2015 2016 2017 2018 2019
@size_at_age_step 2
@size_at_age_dist normal
@size_at_age_miss mean
@size_at_age
```

```
cv 0.1
# age          2     3     4     5     6     7     8     9    10
11    12    13    14    15
male_1979 30.31 35.70 39.36 41.92 42.76 43.85 43.51 43.07 42.57
43.06 42.91 42.71 42.85 43.02
male_1980 30.21 35.38 38.84 41.11 42.44 43.37 44.00 43.62 43.36
43.85 43.84 43.51 43.44 43.45
male_1981 30.31 35.26 38.34 40.15 42.24 43.26 44.22 44.24 43.98
44.38 44.64 44.14 44.03 43.92
male_1982 30.48 35.33 38.18 40.06 42.18 43.13 44.15 44.63 44.56
44.77 45.36 44.62 44.67 44.40
male_1983 30.65 35.54 38.21 40.25 42.21 43.11 44.10 44.85 44.98
45.13 45.92 45.16 45.39 44.93
male_1984 30.78 35.79 38.35 40.48 42.32 43.16 44.11 45.05 45.33
45.51 46.37 45.75 46.05 45.49
male_1985 30.91 35.96 38.54 40.70 42.45 43.20 44.17 45.29 45.67
45.84 46.64 46.27 46.52 46.02
male_1986 31.02 36.11 38.61 40.91 42.55 43.31 44.34 45.55 46.19
46.09 46.70 46.68 46.83 46.46
male_1987 31.00 36.21 38.66 41.03 42.69 43.66 44.58 45.66 46.70
46.09 46.72 47.02 47.12 46.84
male_1988 30.52 36.30 38.80 41.14 42.91 44.04 44.91 45.69 46.97
46.11 46.88 47.34 47.45 47.26
male_1989 30.01 36.09 39.13 41.38 43.16 44.38 45.23 45.82 47.16
46.57 47.12 47.54 47.80 47.72
male_1990 29.79 36.11 39.39 41.79 43.46 44.76 45.63 46.25 47.35
47.10 47.62 47.78 48.24 48.15
male_1991 29.45 35.72 40.19 42.10 43.97 45.09 45.97 46.67 47.42
47.53 48.25 48.15 48.67 48.57
male_1992 28.27 34.99 39.76 42.13 44.37 45.64 46.24 46.94 47.47
47.87 48.76 48.52 49.04 48.96
male_1993 28.02 32.81 38.71 41.75 44.42 46.18 46.40 47.18 47.59
48.18 49.06 48.87 49.36 49.39
male_1994 28.34 31.29 36.36 40.63 44.13 45.98 46.57 47.25 47.61
48.35 49.20 49.33 49.60 49.81
male_1995 28.98 31.19 34.41 38.27 43.07 45.31 46.55 47.20 47.53
48.49 49.21 49.81 49.84 50.01
male_1996 29.30 31.66 34.36 36.35 40.67 44.02 46.13 46.98 47.44
48.46 49.11 49.95 50.05 49.98
male_1997 28.81 32.05 35.12 36.32 38.66 41.77 44.40 46.38 47.24
48.10 48.80 49.66 50.04 49.82
male_1998 28.01 32.12 35.71 37.18 38.45 39.90 42.47 44.93 46.67
47.59 48.08 49.10 49.74 49.56
male_1999 27.67 32.25 35.75 37.94 39.10 39.69 40.80 43.06 45.40
46.93 47.14 48.06 49.26 49.23
male_2000 28.06 32.66 35.76 38.31 39.80 40.36 40.48 41.67 43.87
45.93 46.30 46.73 48.42 48.83
male_2001 28.67 33.36 36.13 38.72 40.25 41.13 40.99 41.35 42.89
44.78 45.61 45.74 47.35 48.05
male_2002 29.03 33.99 37.03 39.24 40.70 41.77 41.71 41.73 42.95
44.05 45.02 45.22 46.50 46.96
male_2003 29.18 34.20 37.95 39.84 41.67 42.28 42.77 42.26 43.57
44.09 44.71 44.95 46.20 46.13
male_2004 29.37 33.91 38.25 40.21 41.83 42.43 43.74 42.82 44.04
44.55 44.83 44.93 46.27 45.76
```

```
male_2005 29.42 33.37 37.66 40.05 41.61 42.34 43.91 43.35 43.99
44.93 45.21 45.32 46.45 45.62
male_2006 29.24 32.73 36.63 39.20 40.65 41.98 43.61 43.62 43.85
45.03 45.51 45.93 46.67 45.54
male_2007 28.85 31.85 35.58 38.02 39.64 41.24 43.02 43.67 43.67
45.05 45.71 46.23 46.91 45.58
male_2008 27.97 30.80 34.43 36.97 39.06 40.59 41.82 43.38 43.28
44.81 45.74 45.77 46.89 45.81
male_2009 27.13 29.96 33.22 36.05 38.57 40.08 40.78 42.70 42.86
44.32 45.24 45.19 45.87 46.14
male_2010 26.81 29.41 32.49 35.25 38.00 39.62 40.51 42.22 42.24
43.86 44.49 44.66 44.80 46.47
male_2011 26.73 29.00 32.35 34.91 37.59 39.29 40.47 42.30 41.95
43.80 43.92 43.96 44.44 46.70
male_2012 26.97 28.95 32.33 35.32 37.54 39.03 40.53 42.61 42.91
44.18 44.06 43.57 44.15 46.72
male_2013 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
male_2014 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
male_2015 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
male_2016 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
male_2017 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
male_2018 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
male_2019 27.87 29.32 32.58 36.08 38.20 39.13 40.78 42.91 43.91
44.79 44.78 43.80 44.10 46.62
female_1979 29.94 36.67 40.26 42.43 43.25 44.13 45.66 46.00 46.23
45.79 46.06 45.82 46.19 46.89
female_1980 30.80 36.34 40.30 42.53 43.86 45.32 46.03 46.44 46.73
46.79 46.53 46.51 46.46 47.01
female_1981 30.93 36.03 40.07 42.60 44.25 45.95 46.25 46.70 46.91
47.44 46.88 46.86 46.73 47.21
female_1982 30.68 36.15 39.86 42.67 44.68 46.27 46.45 46.82 47.15
47.96 47.36 47.21 47.04 47.47
female_1983 30.51 36.38 39.90 42.68 44.95 46.51 46.70 46.94 47.38
48.49 47.85 47.76 47.45 47.85
female_1984 30.54 36.64 39.95 42.53 44.88 46.64 46.94 47.07 47.66
48.94 48.22 48.32 48.16 48.36
female_1985 31.11 37.03 39.75 42.30 44.58 46.52 47.25 47.27 48.00
49.15 48.58 48.70 48.89 48.93
female_1986 31.93 37.39 39.70 41.80 44.30 46.24 47.32 47.77 48.35
49.12 49.10 49.01 49.39 49.50
female_1987 32.23 37.73 40.12 41.52 43.94 46.11 47.33 48.21 48.79
49.25 49.50 49.47 49.83 50.04
female_1988 31.08 37.86 40.75 42.21 43.83 46.34 47.37 48.55 49.30
49.68 49.89 50.03 50.29 50.58
female_1989 29.81 37.40 41.26 43.39 44.57 46.75 47.67 48.92 49.88
50.15 50.28 50.74 50.89 51.06
female_1990 29.77 36.72 41.55 44.32 45.72 47.21 48.05 49.40 50.49
50.84 50.67 51.45 51.61 51.51
female_1991 29.62 36.52 41.51 44.70 46.54 47.71 48.60 49.89 51.13
51.57 51.41 52.02 52.28 51.95
```

```
female_1992 28.52 36.01 41.00 44.65 46.76 48.02 49.27 50.21 51.66
52.29 52.12 52.52 52.72 52.33
female_1993 27.71 34.57 39.97 44.19 46.64 48.35 49.73 50.40 51.86
52.86 52.56 52.87 52.81 52.62
female_1994 27.79 33.40 37.88 43.18 46.31 48.41 50.13 50.48 51.82
52.91 52.65 53.09 52.70 52.77
female_1995 28.19 33.27 36.17 40.82 45.44 47.97 50.18 50.56 51.59
52.78 52.64 52.90 52.63 52.85
female_1996 28.48 33.63 36.15 38.79 43.37 46.62 49.59 50.47 51.21
52.45 52.55 52.90 52.67 52.94
female_1997 28.25 33.88 36.91 38.60 41.59 44.33 47.74 49.87 50.66
51.98 51.79 52.92 52.82 53.10
female_1998 27.77 33.65 37.47 39.21 41.26 42.49 45.63 48.24 49.83
51.18 51.04 52.70 52.95 53.24
female_1999 27.59 33.37 37.50 39.74 41.59 42.50 43.98 46.20 48.36
50.19 50.63 52.30 52.95 53.33
female_2000 27.80 33.51 37.52 39.99 42.05 43.30 44.12 44.91 46.66
48.75 49.96 51.56 52.71 53.29
female_2001 28.07 34.28 37.87 40.37 42.36 44.08 45.14 45.16 45.70
47.84 49.24 50.54 52.11 53.08
female_2002 28.20 35.20 38.65 40.90 42.75 44.63 46.00 46.29 46.07
47.39 48.53 49.67 51.29 52.52
female_2003 28.11 35.66 39.41 41.53 43.61 45.10 46.29 47.07 46.84
47.68 48.19 49.09 50.55 51.71
female_2004 27.93 35.59 39.68 41.98 44.03 45.30 46.38 46.82 47.71
48.23 48.68 48.77 50.22 51.02
female_2005 27.77 35.33 39.23 41.91 44.06 45.28 46.38 46.26 47.74
49.03 49.38 49.15 50.10 50.66
female_2006 27.61 34.92 38.37 41.11 43.11 45.01 46.30 45.86 47.43
49.26 50.15 49.87 50.14 50.42
female_2007 27.39 34.22 37.50 39.96 42.17 44.21 46.03 45.38 47.32
49.01 50.47 50.49 50.36 50.21
female_2008 27.17 33.36 36.62 38.98 41.60 43.50 45.35 45.02 46.95
48.77 50.17 50.60 50.50 50.05
female_2009 27.04 32.70 35.76 38.12 41.07 42.97 44.71 44.85 46.48
48.51 49.64 50.38 50.44 49.94
female_2010 27.06 32.05 35.22 37.29 40.45 42.52 44.37 44.70 45.72
48.24 48.71 50.03 50.43 49.85
female_2011 27.35 32.34 34.88 36.86 39.95 42.19 44.08 44.67 45.04
47.71 47.83 48.84 50.38 49.79
female_2012 28.12 33.02 35.32 36.94 39.78 41.87 43.95 44.93 44.64
47.21 47.72 47.68 50.17 49.79
female_2013 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
female_2014 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
female_2015 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
female_2016 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
female_2017 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
female_2018 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
female_2019 29.16 33.90 36.13 37.83 40.30 41.87 44.18 45.33 45.13
47.10 47.98 47.87 49.97 49.87
```

```
@size_weight
a_male 0.00000000515
b_male 3.092
a_female 0.00000000407
b_female 3.152
verify_size_weight 50 0.8 1 # 50 cm fish weighs between 0.8 and 1 kg
```

Estimation.csl

```
@estimator Bayes
@max_iters  4000
@max_evals 10000
@grad_tol 0.0002 #The default is 0.002

@MCMC
start 0.2
length 15000000
keep 1000
stepsize 0.02
proposal_t True
df 2
burn_in 1000
subsample_size 3000
systematic False

@profile
parameter initialization.B0
n      15
l  200000
u  600000

@relative_abundance TangaroaAcousticMature
biomass True
q TangaroaMatureq
years 1993 1994 1995 1998 2000 2002 2004 2006 2009 2011 2013
step 2
area spawn
ogive TangaroaMatureSel
proportion_mortality 0.5
1993 16060
1994 72168
1995 53608
1998 91639
2000 71749
2002 66034
2004 42236
2006 43843
2009 99521
2011 53299
2013 65487 # ROD revised to 65801 (jan 2013)
cvs_1993 0.24
cvs_1994 0.34
cvs_1995 0.30
```

```
cvs_1998 0.14
cvs_2000 0.17
cvs_2002 0.68
cvs_2004 0.35
cvs_2006 0.32
cvs_2009 0.27
cvs_2011 0.22
cvs_2013 0.25
dist lognormal
cv_process_error 0.001

@relative_abundance TangaroaAcousticImmature
biomass True
q TangaroaImmatureq
years 1993 1994 1995 1998 2000 2002 2004 2006 2009 2011 2013
step 2
area nonspawn
ogive TangaroaImmatureSel
proportion_mortality 0.5
1993 35208
1994  8018
1995 15507
1998  6759
2000  1864
2002   247
2004  5617
2006  3423
2009 24479
2011 14454
2013  8004
cvs_1993 0.25
cvs_1994 0.38
cvs_1995 0.29
cvs_1998 0.20
cvs_2000 0.24
cvs_2002 0.76
cvs_2004 0.16
cvs_2006 0.24
cvs_2009 0.26
cvs_2011 0.17
cvs_2013 0.55
dist lognormal
cv_process_error 0.001

@catch_at ObserverProportionsAtAge
years 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
fishery Trawl
sexed True
plus_group True
#        M2     M3     M4     M5     M6     M7     M8     M9    M10
M11    M12    M13    M14    M15     F2      F3    F4     F5     F6
F7     F8     F9    F10    F11    M12    M13    M14    M15
1979 0.0059 0.0139 0.1321 0.0439 0.0066 0.0065 0.0570 0.0087 0.0130
0.0358 0.0657 0.0601 0.0931 0.1649 0.0028 0.0079 0.0800 0.0240
```

```
0.0093 0.0029 0.0154 0.0000 0.0082 0.0082 0.0144 0.0198 0.0374
0.0626
1980 0.0019 0.0100 0.0254 0.0381 0.0031 0.0260 0.0146 0.0266 0.0000
0.0213 0.0659 0.0517 0.0824 0.3443 0.0003 0.0025 0.0041 0.0334
0.0074 0.0064 0.0095 0.0114 0.0046 0.0130 0.0031 0.0214 0.0358
0.1360
1981 0.1238 0.0080 0.0096 0.0147 0.0227 0.0182 0.0050 0.0235 0.0248
0.0053 0.0212 0.0423 0.0427 0.2575 0.0326 0.0015 0.0116 0.0037
0.0359 0.0075 0.0070 0.0215 0.0170 0.0071 0.0165 0.0206 0.0240
0.1744
1982 0.0648 0.2994 0.0346 0.0024 0.0117 0.0432 0.0039 0.0036 0.0088
0.0178 0.0037 0.0019 0.0019 0.1078 0.0505 0.1348 0.0279 0.0229
0.0020 0.0228 0.0063 0.0048 0.0116 0.0085 0.0075 0.0048 0.0120
0.0781
1983 0.0239 0.2128 0.1646 0.0043 0.0055 0.0108 0.0202 0.0029 0.0000
0.0179 0.0135 0.0000 0.0035 0.1003 0.0094 0.1773 0.1145 0.0076
0.0102 0.0015 0.0218 0.0067 0.0000 0.0038 0.0022 0.0000 0.0015
0.0631
1984 0.0017 0.0287 0.1417 0.1876 0.0297 0.0244 0.0192 0.0415 0.0128
0.0044 0.0039 0.0185 0.0061 0.0951 0.0005 0.0276 0.1280 0.1285
0.0100 0.0038 0.0049 0.0167 0.0056 0.0009 0.0036 0.0095 0.0045
0.0405
1985 0.0202 0.0082 0.0861 0.1896 0.1193 0.0033 0.0063 0.0130 0.0212
0.0157 0.0038 0.0229 0.0119 0.0892 0.0031 0.0036 0.0493 0.1134
0.1250 0.0116 0.0020 0.0018 0.0103 0.0000 0.0055 0.0174 0.0180
0.0283
1986 0.0255 0.0680 0.0264 0.0414 0.1421 0.1195 0.0180 0.0078 0.0112
0.0151 0.0000 0.0089 0.0089 0.0922 0.0065 0.0465 0.0264 0.0218
0.0916 0.1089 0.0121 0.0092 0.0137 0.0112 0.0085 0.0042 0.0050
0.0494
1987 0.0200 0.0949 0.0905 0.0133 0.0244 0.1115 0.0787 0.0093 0.0074
0.0052 0.0115 0.0034 0.0077 0.0501 0.0102 0.0958 0.1099 0.0125
0.0288 0.0765 0.0727 0.0079 0.0058 0.0075 0.0055 0.0035 0.0043
0.0314
1988 0.0813 0.0943 0.0866 0.0704 0.0000 0.0202 0.1200 0.0571 0.0006
0.0110 0.0013 0.0115 0.0055 0.0248 0.0033 0.0750 0.0823 0.0627
0.0038 0.0315 0.0759 0.0404 0.0055 0.0031 0.0043 0.0027 0.0000
0.0249
1989 0.0038 0.1440 0.0758 0.0617 0.0554 0.0000 0.0356 0.0864 0.0637
0.0172 0.0040 0.0077 0.0061 0.0189 0.0007 0.0923 0.0633 0.0543
0.0595 0.0089 0.0152 0.0609 0.0349 0.0133 0.0014 0.0052 0.0013
0.0084
1990 0.0198 0.1070 0.2107 0.0457 0.0405 0.0459 0.0034 0.0104 0.0260
0.0240 0.0062 0.0000 0.0058 0.0099 0.0039 0.0450 0.2625 0.0318
0.0268 0.0210 0.0046 0.0062 0.0193 0.0129 0.0019 0.0024 0.0026
0.0037
1991 0.0000 0.2668 0.0517 0.0428 0.0161 0.0104 0.0061 0.0027 0.0049
0.0074 0.0035 0.0020 0.0001 0.0022 0.0007 0.3521 0.0870 0.0836
0.0178 0.0120 0.0048 0.0021 0.0035 0.0064 0.0052 0.0020 0.0018
0.0044
1992 0.0814 0.0086 0.2553 0.0648 0.0739 0.0142 0.0111 0.0077 0.0024
0.0025 0.0035 0.0038 0.0024 0.0012 0.0141 0.0054 0.2586 0.0684
0.0859 0.0102 0.0094 0.0042 0.0004 0.0036 0.0039 0.0015 0.0000
0.0013
1993 0.0293 0.1831 0.0299 0.1551 0.0295 0.0386 0.0095 0.0000 0.0000
0.0000 0.0020 0.0061 0.0033 0.0000 0.0008 0.1981 0.0258 0.1399
```

```
0.0438 0.0759 0.0046 0.0064 0.0021 0.0015 0.0014 0.0116 0.0002
0.0014
1994 0.0240 0.5952 0.0198 0.0018 0.0185 0.0011 0.0105 0.0000 0.0005
0.0000 0.0000 0.0000 0.0008 0.0000 0.0064 0.2378 0.0487 0.0017
0.0179 0.0049 0.0075 0.0009 0.0003 0.0005 0.0000 0.0000 0.0006
0.0007
1995 0.0037 0.0791 0.3109 0.0124 0.0018 0.0156 0.0020 0.0071 0.0006
0.0002 0.0002 0.0000 0.0000 0.0013 0.0002 0.0291 0.4778 0.0277
0.0011 0.0150 0.0029 0.0082 0.0005 0.0008 0.0003 0.0002 0.0002
0.0010
1996 0.0039 0.0425 0.0728 0.2360 0.0046 0.0007 0.0051 0.0011 0.0009
0.0004 0.0003 0.0002 0.0000 0.0005 0.0017 0.0251 0.1035 0.4724
0.0090 0.0024 0.0098 0.0019 0.0026 0.0010 0.0002 0.0004 0.0000
0.0010
1997 0.0094 0.0203 0.0461 0.0890 0.3210 0.0095 0.0070 0.0094 0.0029
0.0037 0.0002 0.0010 0.0000 0.0002 0.0110 0.0228 0.0483 0.0595
0.3134 0.0115 0.0046 0.0035 0.0020 0.0020 0.0003 0.0009 0.0000
0.0006
1998 0.0136 0.1025 0.0289 0.0343 0.0826 0.2160 0.0041 0.0112 0.0014
0.0044 0.0000 0.0000 0.0005 0.0000 0.0022 0.0335 0.0271 0.0381
0.0734 0.3085 0.0059 0.0031 0.0062 0.0005 0.0019 0.0000 0.0000
0.0000
1999 0.0094 0.0680 0.1257 0.0037 0.0219 0.0433 0.1596 0.0122 0.0024
0.0016 0.0044 0.0040 0.0000 0.0023 0.0026 0.0739 0.1812 0.0075
0.0340 0.0325 0.1908 0.0087 0.0039 0.0028 0.0027 0.0000 0.0000
0.0008
2000 0.0136 0.0598 0.0810 0.1064 0.0150 0.0178 0.0160 0.1426 0.0061
0.0000 0.0063 0.0009 0.0023 0.0014 0.0010 0.0227 0.1447 0.1452
0.0147 0.0210 0.0308 0.1396 0.0038 0.0034 0.0026 0.0008 0.0007
0.0000
2001 0.0192 0.1308 0.0449 0.0687 0.0746 0.0017 0.0200 0.0396 0.0861
0.0040 0.0036 0.0060 0.0018 0.0003 0.0041 0.1179 0.0345 0.0791
0.1085 0.0058 0.0150 0.0458 0.0775 0.0069 0.0014 0.0010 0.0002
0.0012
2002 0.0088 0.0330 0.1523 0.0397 0.0878 0.0621 0.0000 0.0104 0.0192
0.0608 0.0026 0.0000 0.0000 0.0011 0.0000 0.0169 0.1483 0.0195
0.0772 0.0785 0.0083 0.0129 0.0504 0.1004 0.0077 0.0012 0.0000
0.0010
2003 0.0266 0.0504 0.0595 0.1068 0.0321 0.0345 0.0287 0.0057 0.0081
0.0168 0.0586 0.0123 0.0016 0.0022 0.0003 0.0554 0.0674 0.1063
0.0246 0.0696 0.0616 0.0231 0.0080 0.0099 0.0973 0.0254 0.0039
0.0035
2004 0.0225 0.2053 0.0419 0.0336 0.0420 0.0172 0.0155 0.0295 0.0042
0.0000 0.0139 0.0539 0.0000 0.0012 0.0000 0.1590 0.0958 0.0385
0.0564 0.0356 0.0174 0.0274 0.0162 0.0007 0.0134 0.0549 0.0020
0.0020
2005 0.0000 0.1409 0.1645 0.0460 0.0109 0.0221 0.0067 0.0105 0.0127
0.0040 0.0031 0.0074 0.0089 0.0052 0.0000 0.1235 0.2360 0.0665
0.0212 0.0169 0.0121 0.0071 0.0213 0.0121 0.0057 0.0049 0.0273
0.0026
2006 0.0927 0.0473 0.1319 0.1360 0.0544 0.0222 0.0059 0.0228 0.0165
0.0169 0.0107 0.0031 0.0000 0.0361 0.0000 0.0207 0.0728 0.1494
0.0371 0.0345 0.0161 0.0123 0.0085 0.0096 0.0010 0.0000 0.0027
0.0386
2007 0.0189 0.0482 0.0494 0.0993 0.1396 0.0308 0.0322 0.0085 0.0064
0.0066 0.0083 0.0059 0.0000 0.0121 0.0000 0.0290 0.1283 0.1365
```

```
0.1028 0.0659 0.0104 0.0087 0.0096 0.0066 0.0042 0.0026 0.0018
0.0275
2008 0.0182 0.0175 0.0749 0.0605 0.0935 0.1132 0.0540 0.0204 0.0078
0.0048 0.0046 0.0030 0.0027 0.0190 0.0001 0.0046 0.0861 0.0791
0.0583 0.1286 0.0762 0.0274 0.0101 0.0050 0.0035 0.0019 0.0004
0.0246
2009 0.0532 0.2327 0.0000 0.1067 0.0174 0.0576 0.0516 0.0136 0.0096
0.0003 0.0044 0.0000 0.0020 0.0078 0.0055 0.1474 0.0000 0.1083
0.0584 0.0383 0.0198 0.0501 0.0067 0.0005 0.0007 0.0017 0.0009
0.0047
2010 0.0000 0.1160 0.2388 0.0474 0.0128 0.0153 0.0195 0.0250 0.0217
0.0044 0.0022 0.0022 0.0021 0.0048 0.0002 0.0551 0.2382 0.0857
0.0174 0.0187 0.0222 0.0172 0.0179 0.0067 0.0033 0.0003 0.0011
0.0040
2011 0.0026 0.0023 0.0910 0.2497 0.0262 0.0019 0.0155 0.0064 0.0311
0.0024 0.0050 0.0012 0.0009 0.0048 0.0007 0.0225 0.1213 0.3280
0.0225 0.0092 0.0163 0.0055 0.0163 0.0043 0.0052 0.0027 0.0016
0.0029
2012 0.0020 0.1542 0.0214 0.0728 0.1642 0.0222 0.0095 0.0014 0.0071
0.0164 0.0055 0.0021 0.0033 0.0013 0.0022 0.1236 0.0346 0.0759
0.1835 0.0479 0.0046 0.0103 0.0089 0.0110 0.0064 0.0042 0.0011
0.0023
2013 0.0049 0.0006 0.2520 0.0143 0.0787 0.0828 0.0154 0.0087 0.0002
0.0034 0.0129 0.0031 0.0000 0.0012 0.0059 0.0000 0.2590 0.0223
0.0681 0.0904 0.0233 0.0190 0.0107 0.0047 0.0093 0.0040 0.0014
0.0038
N_1979  12  # 150
N_1980  16  # 200
N_1981  41  # 495
N_1982  41  # 494
N_1983  35  # 423
N_1984  47  # 571
N_1985  33  # 404
N_1986  47  # 568
N_1987  58  # 705
N_1988  54  # 656
N_1989  55  # 664
N_1990  60  # 724
N_1991  161 # 1941
N_1992  72  # 872
N_1993  40  # 488
N_1994  122 # 1474
N_1995  135 # 1632
N_1996  133 # 1598
N_1997  69  # 833
N_1998  48  # 584
N_1999  61  # 734
N_2000  26  # 318
N_2001  47  # 574
N_2002  28  # 343
N_2003  58  # 704
N_2004  24  # 296
N_2005  62  # 745
N_2006  26  # 318
N_2007  46  # 562
N_2008  55  # 670
```

```
N_2009  20  # 246
N_2010  75  # 908
N_2011  56  # 675
N_2012  69  # 832
N_2013  55  # 669
dist multinomial

@estimate
parameter q[TangaroaMatureq].q
lower_bound 0.09
upper_bound 3.00
prior lognormal
mu 0.68
cv 0.77

@estimate
parameter q[TangaroaImmatureq].q
lower_bound 0.01
upper_bound 3.00
prior uniform

@estimate
parameter initialization.B0
lower_bound  30000
upper_bound 1500000
prior uniform-log

# Q METHOD

@q_method free

@q TangaroaMatureq
q .5

@q TangaroaImmatureq
q .3


@estimate
parameter initialization.Cinitial_male
same initialization.Cinitial_female
lower_bound  2e2  2e2  2e2  2e2  2e2  2e2  2e2  2e2  2e2  2e2  2e0
2e0  2e0  2e0
upper_bound  2e9  2e9  2e9  2e9  2e9  2e9  2e9  2e9  2e9  2e9  2e9
2e9  2e9  2e9
prior uniform

@estimate
parameter migration[toSpawn].rates_all
lower_bound 0.001 0.001 0.001 0.001 1
upper_bound 0.999 0.999 0.999 0.999 1
prior uniform


@estimate
parameter recruitment.YCS
```

```
#YCS_years   1977  1978  1979  1980  1981  1982  1983  1984  1985
1986  1987  1988  1989  1990  1991  1992  1993  1994  1995  1996
1997  1998  1999  2000  2001  2002  2003  2004  2005  2006  2007
2008  2009  2010  2011
lower_bound 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 1
upper_bound   10   10  10   10   10   10   10   10   10   10   10
10   10   10   10   10   10   10   10   10   10   10   10   10   10
10   10   10   10   10   10   10   10   10      1
prior lognormal
mu               26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130
26489122130
cv             2980.958 2980.958 2980.958 2980.958 2980.958 2980.958
2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958
2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958
2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958
2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958
2980.958


@catch_limit_penalty
label Penalty-CatchLimitTrawl
log_scale True
fishery Trawl
multiplier 100

@estimate
parameter recruitment.steepness
lower_bound     0.21
upper_bound     1
prior beta
mu 0.85
stdev 0.1

@estimate
parameter natural_mortality.all
prior normal
mu 0.20
cv 0.15
lower_bound 0.1
upper_bound 0.4
```