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The 2014 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 3 and development of new management procedures

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Haist, V.; Breen, P.A.; Edwards, C.T.T. (2015). The 2014 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 3, and development of new management procedures.

***New Zealand Fisheries Assessment Report 2015/28.* 73 p.**

This document describes a new stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 3 and describes evaluations of new operational management procedures. The work was conducted by a stock assessment team contracted by the New Zealand Rock Lobster Industry Council Ltd.

The stock assessment was made using the length-based multi-stock model MSLM. The Rock Lobster Fishery Assessment Working Group oversaw this work, and all technical decisions were agreed beforehand or subsequently approved (and sometimes changed) by that group. The model was fit to CPUE indices, size frequency data, tag-recapture data and puerulus settlement indices. This document describes the procedures used to find acceptable base cases and shows the model fits. The assessment was based on Markov chain – Monte Carlo (McMC) simulations, and the document describes the diagnostics for these and shows the results of McMC sensitivity trials. Short-term projections were made at the current estimated levels of catch.

The assessment showed that current vulnerable biomass is well above *Bmsy* and *Bmin* reference levels and that current fishing intensity is below *Fmsy*. At current catch levels, biomass was projected to decline based on recent recruitments but projected to remain well above reference levels.

The assessment model was used as the basis for an operating model to evaluate the performance of management procedures for CRA 3, which has had a management procedure to determine TACs for five years. At MPI request, the rules tested determined annual TACC as a function of offset-year CPUE. These rules were all “plateau” rules; some were industry-designed and some were conventional “plateau step” rules. Each rule was tested with 1000 20-year simulations, based on the McMC posteriors, to address parameter uncertainty, and with stochastic variation in CPUE observation error and in recruitment to address environmental uncertainty. Rule behaviour under alternative operating model assumptions was tested using four robustness trials. The document explores the major trade-offs among indicators. Final management procedure candidates were presented to the National Rock Lobster Management Group.

To make it accessible to the non-specialist, this document also provides a glossary of terms used in the stock assessment and management procedure evaluations.

1. INTRODUCTION

This work addressed Objectives 4 and 5 of the Ministry for Primary Industries (MPI) contract CRA2012-01B. This three-year contract, which began in April 2013, was awarded to the NZ Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted Objectives 4 and 5 to the authors of this report.

Objective 4 - Stock assessment: To estimate biomass and sustainable yields for rock lobster stocks

Objective 5 - Decision rules: To evaluate new management procedures for rock lobster fisheries

The National Rock Lobster Management Group (NRLMG) determined that both CRA 1 and CRA 3 stocks should be assessed in 2014. Data were compiled for both stocks by a team comprising Paul Starr (Starrfish), D'Arcy Webber (Quantifish) and Paul Breen (Breen Consulting). CRA 1 was then assessed by Paul Starr and D'Arcy Webber, and CRA 3 was assessed by Vivian Haist (Haist Consultancy), Paul Breen and Charles Edwards (NIWA), with close communication and discussion between the two teams. New graphic routines were developed by D'Arcy Webber and Charles Edwards. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

The previous stock assessment of CRA 3 was in 2008 (Breen et al. 2009a). Operational management procedures (MPs) were developed for CRA 3 in 2009 (Breen et al. 2009b), in a procedure that was essentially a fresh stock assessment. At that time the CRA 3 stock was depleted and needed to be rebuilt; reduced catches and probable strong recruitment (see below) brought about a strong increase in annual CPUE.

This study also developed management procedures for CRA 3. Management procedures are extensively simulation-tested decision rules: see Johnston & Butterworth (2005) and Johnston et al. (2014) for discussion of management procedures used to manage rock lobsters in South Africa. Management procedures are now a major part of New Zealand rock lobster management (Bentley et al. 2003b; Breen et al. 2009b). They were used to rebuild the depleted CRA 8 stock in New Zealand and to manage the volatile CRA 7 stock (Starr et al. 1997; Bentley et al. 2003a; Breen et al. 2008; Haist et al. 2013); a voluntary management procedure was used to govern ACE shelving in CRA 4 to rebuild a badly depleted stock (Breen et al. 2009c) and was revised by Breen et al. (2012); a management procedure was adopted for CRA 5 for the 2012–13 season, after using a voluntary management procedure designed to maintain high abundance (Breen 2009a); a management procedure was adopted for CRA 3 in 2010 (see Breen et al. 2009a). Management procedures were explored with a surplus-production model for CRA 9 (Breen 2011, 2014) and CRA 6 (Breen 2009b).

Management in CRA 3 and other New Zealand rock lobster stocks is an example of "results-based" management, whereby responsibility for producing specified resource outcomes has been delegated by government to stakeholders (see Neilsen et al. 2015). With some reservations, this approach has been largely successful for New Zealand lobster stocks (Yandle 2008; Miller & Breen 2010).

The CRA 3 fishery extends from East Cape south to the Wairoa River (see Figure 1). The current 389.95 t TAC comprises allowances of 20 t for recreational catch, 20 t for customary harvest, 89 t for illegal removals and a TACC of 260.95 t distributed among 43 quota share owners. In the 2013 fishing year[1], 25 vessels reported CRA 3 landings. There is significant Iwi involvement in quota share ownership and fishing and rock lobsters have great cultural significance to local Maori. The commercial harvest has an approximate landed value of $18.3 million based on average port price. There are two processing plants in Gisborne and product is also shipped to Wellington, Tauranga and Auckland for processing and export.

[1] The fishing year runs from 1 April through 30 March; our convention is to name the year by the first portion, *viz.* 2013–14 is called "2013".

Data for this work are described by Starr et al. (2015). This document describes the base case stock assessment, MPD and McMC sensitivity trials, the projection model, management procedure evaluations and the final harvest control rules that were submitted to the NRLMG.

Technical terms used here are defined in the Glossary.

2. BASE CASE MPD AND SENSITIVITY TRIALS

2.1 Model

The multi-stock length-based model (MSLM) was described by Haist et al. (2009). During the previous stock assessment of CRA 3 (Breen et al. 2009a), a difference in growth rates between the older and newer tag-recapture data was discovered. The model was revised during the 2008 stock assessment on an *ad hoc* basis that was not compatible with the multi-stock capability of the model. For this assessment, the model was revised to incorporate the change on a generalised basis; growth in two user-specified epochs can be estimated for any stock. Other updates for this assessment included coding new indicators, allowing growth parameters to be initialised or fixed separately for males and females, changing the small constant added to the likelihood for fitting length frequency data (LFs) when cells are zero and making minor changes to output formats.

The model is implemented in AD Model Builder (Fournier et al. 2012). The model is an integrated model (see Maunder & Punt 2013; Punt et al. 2013a) that estimates all structural parameters by fitting to several data sets simultaneously. CPUE is an exception to this: it is standardised outside the model and the model fits to the standardised indices. It might be preferable to estimate the explanatory variables for CPUE along with the other parameters (Maunder 2011) but this is not done for logistic reasons.

The model time step can be specified and can vary during the period being simulated. The model's number and width of size bins is specified. Fishing is modelled by taking into account the observed catch, minimum legal sizes (MLS) that can change during the period simulated, estimated seasonal vulnerability and estimated size-selectivity of the fishing gear that can vary over time. The model fits the catch that is limited by MLS and a restriction on landing ovigerous females, comprising the commercial and recreational catches, and separately fits the catch not limited by these regulations, comprising the illegal and customary catches.

In each time step, the number of male, immature female and mature female lobsters in each size class is updated as a result of annual recruitment to the model, to a specified mean size with specified variation. Recruitment can vary over time. Natural mortality is estimated but assumed to be constant over time and among sizes and sexes. Handling mortality of returned lobsters (undersized and berried females) is assumed.

A growth transition matrix, based on estimated sex-specific growth parameters, specifies the probability of an individual lobster remaining in the same size bin or growing into each of the other size bins, including smaller ones. Maturation of females is described by a two-parameter logistic curve.

After finding a base case, the stock assessment estimates and their uncertainty are made with Markov chain – Monte Carlo simulations (McMC). Although this is time-consuming, it is recommended as the default method for uncertainty estimates in stock assessments (Magnusson et al. 2012).

2.2 Model parameters

The list below provides a description of the model's estimated parameters using their "shorthand" names instead of the more awkward notation used in the model's formal description:

- $\ln(R0)$: the natural logarithm of average recruitment

- ln(*qCPUE*) and ln(*qCR*): the natural logarithms of catchability coefficients for the CPUE and CR abundance indices
- *M*: the instantaneous rate of fishing mortality
- *Rdev*s: annual recruitment deviations that allow annual recruitment to be less than or greater than average
- *sigmaR*: the standard deviation of *Rdev*s in natural log space
- *CPUEpow*: a parameter that determines the shape of the relation between CPUE and abundance (1 implies linear)
- *Mat50*: size at which 50% of immature females become mature in a year
- *Mat95add*: the difference between *mat50* and *mat95*
- *Galpha*: annual growth increment at 50 mm TW
- *GBeta*: annual growth increment at 80 mm TW (calculated from *Galpha* and *Gdiff*)
- *Gdiff*: the estimated ratio of *GBeta* to *Galpha*
- *GCV*: the relation between the expected growth increment and its standard deviation
- *Gshape*: a growth shape parameter: 1 gives a linear relation between increment and initial size while values greater than 1 give a curve concave upwards
- *GrowthDD*: a density-dependent growth parameter (described below)
- *StdObs*: standard deviation of observation error
- *StdMin*: the minimum standard deviation of growth
- *Vuln*s: a set of four parameters that estimate the vulnerability of a sex class in a season relative to that in a specified sex and season
- *Sel_L*: the shape of the left-hand side of the selectivity-at-length curve
- *SelMax*: the size at which selectivity-at-length is maximum
- *Sel_R*: the shape of the right-hand side of the selectivity-at-length curve.

The *GrowthDD* parameter can take values between 0 and 1. When it is active, the predicted growth increment is multiplied by the factor

$$1 - GrowthDD\left(B_t / B0\right)$$

where B_t is the total biomass in period *t* and $B0$ is the initial total biomass.

2.3 Model options and fitting

The model was fit to two CPUE indices (the older one is referred to as CR) using lognormal likelihood, to LFs using multinomial likelihood, and to tag-recapture data using robust normal likelihood. It was fit to puerulus settlement indices with lognormal likelihood on an experimental basis described below. The data sets are described by Starr et al. (2015). Data sets were weighted iteratively to obtain standard deviations of normalised residuals (sdnrs) close to 1 or median absolute residuals (MARs) close to 0.67. For the LF data, the weighting scheme of Francis (2011) was used, where the fits to mean length were used to determine LF weighting , although the fit to mean length was not used in the likelihood.

For this assessment a single stock was assumed. The model simulation began at an unfished equilibrium in 1945, using a one-year time step through 1978 and then two time steps, autumn-winter (AW) from April through September and spring-summer (SS). *Rdev*s were estimated for all years through 2011 or 2013. The model used instantaneous fishing dynamics (the Baranov equation), with *F* determined from *M*, model biomass and known catch using Newton-Raphson iterations (five iterations in final models). We assumed double-normal fishery selectivity, with selectivity estimated separately for two epochs: 1945–92 and 1993–2013.

Growth was estimated separately for 1945–81 and 1995–2013, with a linear transition in the intervening years. We used the Schnute-Francis growth model (the inverse logistic (Haddon et al. 2008) is an alternative coded model option but was not explored). The relation between CPUE and vulnerable biomass was assumed to be linear.

Model options for density-dependent growth, stock-recruitment and movements were not used.

2.4 Base case MPD

As in previous assessments we used a lognormal prior on *M* with a mean of 0.12. Because there was little information about maturation in the LF data, we fixed the maturation priors, using the mean of the CRA 2 (Starr et al. 2014) and CRA 4 (Breen et al. 2012) median estimates. One of the two growth parameters *Gshape* and *GCV* was fixed and the other estimated in the two final base cases. We put a normal prior on *SelMax* with its mean near MLS. The maximum sex/season vulnerability was assumed to be for males in SS. *Vuln1* estimated male vulnerability in AW, *Vuln2* immature females in AW, *Vuln3* all females in SS and *Vuln4* mature females in AW.

We experimented with dataset weights, with fixing various parameters, using additional priors, using a non-standard size structure starting at 44 mm TW instead of 30 mm, and excluding a subset of the tag-recapture data based on a pattern in the residuals. We rejected all these approaches except for those just described. Much of the exploratory fitting was to find the median of the posterior density (MPD) fits with a positive definite Hessian matrix (pdH), which is necessary for running McMCs. Not all explorations were documented formally; probably 150 exploratory fits were made.

We found two alternative base cases: one with *GCV* fixed at a value suggested by exploratory fitting with only the tagging data (Breen, unpublished data) and *Gshape* estimated, and the other with *Gshape* fixed, again near a value suggested by exploratory fitting, and *GCV* estimated. The fixed quantities used in the final base cases are shown in Table 1 and the estimation details are shown in Table 2 for the two base cases. In the fixed *GCV* base case, *Rdev*s were estimated through 2011; in the fixed *Gshape* base case they were estimated through 2013 because runs were not pdH otherwise.

The fixed *GCV* base case put more weight on the tag-recapture data than the fixed *Gshape* base case, (Table 3) although the diagnostics sdnr and MAR were similar. The fixed *GCV* base case also put more weight on CPUE and showed a higher sdnr.

For both base cases, *M* was considerably higher than the prior mean. The fixed *GCV* base case had slightly lower *M*, lower recruitment but higher *MSY*. The fixed *Gshape* base case had higher *F* at *Bmsy* and showed slower growth between recruitment to the model and recruitment to the fishery.

For both base cases, predicted CPUE (Figure 2) was less than observed at the SS peak and for the most recent two years; the fixed *GCV* base case showed increasing predicted CPUE between 2012 and 2013 while the fixed *Gshape* base case showed a decline. The residuals (Figure 3) showed no obvious pattern that would cause concern. The fit to historical catch per day, CR, was good and similar for both base cases (Figure 4).

Typical fits to LFs are shown in Figure 5 and Figure 6; they were acceptable but the residuals by season and sex showed some pattern near the MLS for both males and mature females in both models (Figure 7). This pattern is common in results from the MSLM model. The distributions of normalised residuals (Figure 8) showed more zero and small residuals than were predicted by a normal distribution and showed long tails of large residuals.

Fits to proportion-at-sex (Figure 9 and Figure 10) followed the trends in the observed values but did not reproduce the extreme values; residuals are shown in Figure 11 and the Q-Q plots in Figure 12. Fits to mean length (Figure 13) were similar in the two base cases and again, they followed the trends but (especially for mature females) did not follow the full range of the trend.

Predicted vs. observed sizes at recapture in the tag data (Figure 14) were also similar for the two models; the relations are messy, reflecting much variation in the data (see Starr et al. 2015). Q-Q plots (Figure 15) of the residuals are also messy, but these assume normally distributed residuals whereas the fitting used was robust normal likelihood. Patterns of residuals vs. size at release (Figure 16 and Figure 17) were similar for the two models. The predicted increments-at-size and their variability are compared for the two models in Figure 18.

Recruitment trajectories were different in the two base cases (Figure 19). In the fixed *GCV* base case, there was a strong episode involving seven years of good recruitment near 1980, very poor recruitment in 2001 and 2002 and a small spike in 2009, but recruitment was clearly reduced after 1983. In the fixed *Gshape* base case, there were three episodes of good recruitment of about equal height and higher interannual correlation than in the other base case. This difference led the RLFAWG to accept two base cases rather than choosing a single base case.

The initial (unfished) equilibrium size structure is shown in Figure 20; the two models are similar. Estimated exploitation rates (Figure 21) were higher for the fixed *GCV* base case. Selectivity curves are compared in Figure 22.

Vulnerable biomass (Figure 23) showed a higher trajectory with more contrast in the fixed *Gshape* base case. Figure 24 shows recruited biomass (above the MLS, using the recent seasonal MLS) by sex category. The two base cases are similar for recent years but show differences in the relative importance of males and mature females for earlier years.

2.5 Puerulus randomisation trials

When the model was fit to puerulus indices, there was little effect on estimated and derived parameters (Table 4). As in previous stock assessments we conducted a statistical test of whether there was a significant signal in the puerulus data. Both base cases were first fit to the puerulus data and the total objective function value was recorded. Then the model was fit to 1000 sets of randomised puerulus indices: the data were randomly mixed (sampled without replacement). The null hypothesis of no signal in the data predicts that the function value from the real data will lie somewhere in the centre of the distribution of values; the research hypothesis (significant signal) predicts that the function value obtained with real data will lie in the lower tail of the distribution. We made this test for several values of lag between puerulus settlement and recruitment to the model at a mean size of 32 mm TW.

Results (Table 5) did not show the function value close to the tail for either base case at any lag. The simple correlations between the puerulus indices and the MPD recruitment, using the appropriate lag, were not strong (e.g. Figure 25).

Based on these results, we could not reject the null hypothesis and we did not use the puerulus indices further in this stock assessment.

2.6 MPD sensitivity trials

Some MPD sensitivity trials were requested by the RLFAWG and we made additional ones to test our modelling choices. A major uncertainty in the data was with non-commercial catch, both recreational catch estimates (perhaps too low because of the mechanics of the survey, see Starr et al. 2015) and illegal estimates. We explored removing data sets one at a time to see if any one data set had a disproportionately high effect, and we tested the effects of other modelling choices. The trials were:

- fitting to double the estimated recreational catch
- fitting to a doubled illegal catch vector
- fitting to a halved illegal catch vector
- not fitting to CPUE
- not fitting to LFs
- not fitting to CR
- not fitting to tags
- fitting with *M* fixed to 0.12 (requested by the RLFAWG)

- fitting with growth density-dependence estimated
- fitting with the LF record weights not truncated between 1 and 10 (see Starr et al. 2015)
- fitting with *CPUEpow* estimated
- fitting with Newton-Raphson iterations reduced to 3
- fitting with Newton-Raphson iterations increased to 5 for fixed growth shape or reduced to 4 for fixed growth CV
- fitting with logistic selectivity instead of double-normal

Results (Table 6 and Table 7) did not differ greatly between the two models. Only the trials with datasets removed were substantially different from the base cases; it was particularly reassuring that the choice of selectivity model did not affect the results much (see Punt et al. 2014, who consider the selectivity model to be a major source of uncertainty). Removing LFs and tags had the greatest effects. Removing either of these data sets caused *M* to increase. Removing the tag data caused changes in the growth parameter estimates, but the *Galpha* estimates remained in the same general locus as in the base case, suggesting that LF data have good information about growth.

The effects of removing datasets on recruitment trajectories were greatest (Figure 26) when CPUE was removed and least when LFs were removed. The effects on vulnerable biomass (Figure 27) were less than those on recruitment, especially for the period after 1979, and again the removal of CPUE had the largest effect.

3. BASE CASE MCMCS

Both base cases were taken forward to McMCs. For both, single chains of five million simulations were started from the MPD estimates and 1000 samples were saved. These runs used five Newton-Raphson iterations for both base cases. Projections were made for three years to the start of 2017.

Traces (Figure 28) showed some problems, especially associated with *GBeta* for females in the fixed *Gshape* model – there are few data that allow estimation – but were considered acceptable by the Plenary. Diagnostic plots are shown in Figure 29 and the posteriors of estimated and derived parameters are compared with the MPD estimates in Figure 30.

Fits to CPUE (Figure 31 and Figure 32) and the recruitment trajectories (Figure 33) showed patterns that were noted above for the MPD fits. Vulnerable biomass trajectories (Figure 34) were similar in both base cases except that the fixed *Gshape* base case had higher biomass and a stronger downturn in biomass in the projected years. Total biomass trajectories are shown in Figure 35 and both base cases estimated that current total biomass is a high proportion of the unfished total biomass.

Base case McMC posterior distributions of estimated parameters are shown in Table 8.

3.1 Assessment indicators

Indicators requested by MPI and the RLFAWG included several based on vulnerable biomass: current (2014) biomass *B2014*, projected biomass *B2017* and the minimum of the vulnerable biomass trajectory after 1979, *Bmin*. These were all start-of-season AW biomass, which does not include mature females. Vulnerable biomass takes MLS, selectivity and sex/seasonal vulnerability into account, and is the biomass available to the fishery. In CRA 3, MLS for males for the commercial fishery is 52 mm in AW, and reverts to 54 mm in SS. Vulnerable biomass was calculated with the appropriate MLS for the season.

Some previous assessments for CRA 3 have used *Bref*, the average of vulnerable biomass from 1974–79. When the first assessment was done, this appeared to be a relatively stable period. However, in this assessment the biomass was declining strongly in this period (see Figure 23). The RLFAWG agreed that *Bref* should be reported but that it was not a useful indicator.

A minor loss of realism was caused by assuming that the recreational fishery used the same MLS as commercial: 52 mm TW in AW. Addressing this would involve major recoding. The problem affects only CRA 3 and is minor because only 10% of the recreational catch is assumed to be taken in AW.

Bmsy and *MSY* were estimated in deterministic 50-year simulations that started at the 2014 biomass estimates. The 2013 non-commercial catches were assumed to remain constant, and the simulations used the 2013 catch splits between AW and SS. Growth was based on the second growth epoch and recruitment was based on *R0* modified (reduced) by the addition of marine reserves. A series of multipliers on *F* was applied, and *MSY* was the maximum commercial catch; *Bmsy* was the biomass from which *MSY* was taken. *Fmult* was the multiplier on 2013 *F* that gave *MSY*. *CPUEmsy* was the CPUE associated with *MSY*.

Spawning stock biomass *SSB* was the biomass of all mature females at start of AW; *SSBmsy* was the biomass associated with *MSY*. *SSB0* was the spawning stock biomass at unfished equilibrium.

Biomass and spawning stock biomass were projected for three years using the same assumptions as described for MPD projections: recruitment was based on the most recent 10 years, constant fishing patterns and non-commercial catches.

USL was the exploitation rate on the size-limited (SL) stock and *UNSL* was the exploitation rate on the non-size-limited (NSL) stock.

New for 2014: *Btot* and *Ntot* were the biomass and numbers of all fish without regard to MLS, selectivity or vulnerability.

As well as the simple indicators, the RLFAWG requested the posterior distribution of ratios, for instance the ratio of current biomass to *Bmsy*, and the probabilities that various propositions were true in the McMCs.

3.2 CRA 3 stock assessment

The posteriors of assessment indicators are shown in Table 9. As in the MPDs, the fixed *Gshape* base case had higher biomass estimates than fixed *GCV*. Both base cases showed median biomass well above *Bmin* (roughly 3 to 3.5 times) with no simulation result with biomass less than *Bmin*. Both base cases showed current biomass roughly 3 to 4.5 times above *Bmsy* with no simulation less than *Bmsy*. *MSY* was higher in the fixed *GCV* base case (240 t) than in the fixed *Gshape* base case (210 t). Vulnerable biomass was projected to decline by a median of 15% in the fixed GCV base case and 31% in the fixed *Gshape* base case, but was projected to remain well above *Bmin* and *Bmsy* with high probability. The CPUE associated with *Bmsy* was very low from both base cases.

Spawning stock biomass was projected to remain near its current level by both models. The current level had a median of 70% (fixed *GCV*) or 100% (fixed *Gshape*) of the unfished level and about 1.5 times *SSBmsy* in both base cases. The probability that *SSB* was or was projected to be less than 20% *SSB*) was zero.

Total biomass and numbers, which were new indicators introduced by MPI for this stock assessment, were both relatively high. Total biomass was 50% (fixed *GCV*) to 67% (fixed *Gshape*) of the unfished level, and total numbers were 76% (fixed *GCV*) or 91% (fixed *Gshape*) of unfished levels.

Based on these indicators, there appeared to be no sustainability concerns for this stock.

The phase diagram of fishing intensity vs. biomass is shown in Figure 36. This “snail trail” is a plot developed by the Stock Assessment Methods Working Group, showing the median spawning biomass on the x-axis and median fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go.

Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock *SSB0*. *SSB0* is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution.

The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gave *MSY* was *Fmsy*, and the multiplier was *Fmult*.

Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

For each base case, these plots show the current stock well above *SSB0* and fishing intensities well below *Fmsy*. The stock history varies between the two base cases: in the fixed *GCV* base case, fishing intensity was well above *Fmsy* for several years in the 1980s, while *SSB* was never substantially less than *SSBmsy*. Conversely, in the fixed *Gshape* base case the fishing intensity was never above *Fmsy* but *SSB* was well below *SSBmsy* for about a decade in the 1970s.

3.3 McMC sensitivity trials

Four McMC sensitivity trials were run for each base case. In the first, at the request of the RLFAWG, *M* was fixed to the mean of the prior, 0.12. For both base cases it was not possible to obtain an MPD that was pdH with *M* fixed to 0.12, so the McMC was made using the covariance matrix from runs with *M* fixed to 0.20. The second trial used a uniform prior on *M*; for the fixed *Gshape* base case, pdH could not be obtained and the covariance matrix from the base case simulation was used.

In the third trial, the models were fit to the puerulus indices with a lag of two years between settlement and recruitment to the model at 32 mm TW. In the fourth trial, instead of estimating growth rates separately from the earlier and later epochs used by the base cases, we fit only one set of growth parameters. This trial was made after inspection of the mean residuals from the tag-recapture data plotted against year, illustrated for the fixed *GCV* base case in Figure 37. When growth was estimated from two epochs separately, the average residuals were near zero overall for each epoch, but there was a pattern in the second epoch: the earlier residuals were negative and the later ones strongly positive. This might suggest that growth has changed within the second growth epoch, 1996–2013.

The lower part of Figure 37 shows the mean residuals from the MPD fit using only one growth epoch. As expected this shows higher residuals (faster than predicted growth) in the earliest years, negative residuals for 1996–2008 and some positive residuals in the most recent few years. This was considered worth exploring with an McMC sensitivity trial.

The overall effect on parameter estimates (Table 10) was small. In the single growth epoch trial, growth increment parameters for males were less than in the first epoch of the two-epoch base case but were greater than in the second epoch. The trials involving *M* and puerulus had little effect on growth and other parameters.

Assessment indicators (Table 11) showed no serious deviations from the base cases in these trials, and the stock assessment conclusions reported were not challenged by these trials. Recruitment trajectories were affected most by the one-epoch growth trial in the fixed *Gshape* set (Figure 38). Vulnerable biomass varied among these trials, but the shape of the trajectories did not (Figure 39). Total biomass

(Figure 40) varied greatly among the trials, more in the early years than in the recent years, and again the largest effect was seen in the one-epoch growth trial for the fixed *Gshape* simulations.

4. MANAGEMENT PROCEDURE EVALUATIONS

4.1 Operating model

Operational management procedures (MPs) were developed for CRA 3 in 2009 (Breen et al. 2009b) and one was selected, setting the TAC for 2010–11 through 2013–14. Normally, MPs are used for five years and then re-evaluated. The 2014 project evaluated a suite of new management procedures. At MPI's request, we evaluated rules that used standardised CPUE (collated with the F2-LFX procedure, see Starr et al. 2015) to set a TACC.

To do this, both base case stock assessment models were extended to make 20-year projections that set the TACC in a procedure that was essentially a fresh stock assessment. The commercial catch was determined by the TACC, in turn set each year under the harvest control rule being tested; recreational catch was determined by using the average recreational exploitation rate calculated (for each sample of the joint posterior) for 1979–2013 and assumed to be taken 90% in SS; customary catch was assumed to be 20 t and assumed to be taken 90% in SS; illegal catch was assumed to be 89.5 t and had the same catch split as the commercial catch.

The proportion of catch taken in AW was assumed to be related to AW CPUE (Figure 41) and was predicted for each year from the start-of-season AW vulnerable biomass and the model's *qCPUE*. Observation error added to the model CPUE was based on the residuals in CPUE seen in the minimisation for each sample of the joint posterior.

In real life, MPs are driven by offset-year CPUE, based on the year from 1 October through 30 September. The model estimated this CPUE by taking the mean of CPUE from the AW season in the preceding fishing year and from the SS season in the year before that. This procedure appears to be reliable: the relation between the result and the observed CPUE is linear with slope near 1 and intercept near zero (Figure 42).

The operating model comprised all the samples of the joint posterior obtained in base case stock assessment McMCs: each rule was evaluated with each of the 1000 samples of the joint posterior.

4.2 Harvest control rules

Two families of rules were evaluated. The CRA 3 industry proposed a rule (Figure 43). This was like a "plateau slope" rule of the form currently used in CRA 7 and CRA 8, but with two stages before the plateau instead of one. This was coded as a generalised rule type (type 6) in MSLM, and operates as follows. The parameters are:

par1	rule type (in this case, 6)
par2	CPUE corresponding with inflection point (kg/potlift)
par3	CPUE corresponding with left edge of plateau (kg/potlift)
par4	CPUE corresponding with right edge of plateau (kg/potlift)
par5	TACC while CPUE is on the plateau (t)
par6	slope parameter (t)
par7	TACC when CPUE = *par2* (t)
par8	minimum TACC change threshold (as a proportion of preceding TACC)

and they are applied as follows:

$$TACC_{y+1} = \frac{I_y \, par7}{par2} \qquad \text{for } I_y \le par2$$

$$TACC_{y+1} = par7 + (par5 - par7)\left(\frac{I_y - par2}{par3 - par2}\right) \quad \text{for } par2 < I_y \le par3$$

$$TACC_{y+1} = par5 \quad \text{for } par3 < I_y \le par4$$

$$TACC_{y+1} = par5 + par6\left(\frac{I_y - par4}{0.5}\right) \quad \text{for } I_y > par4$$

where $TACC_{y+1}$ is the provisional TACC (before thresholds operate) and I_y is the CPUE in the preceding year. The specific rule proposed by industry in September had *par2* = 1 kg/potlift, *par3* = 2 kg/potlift, *par4* = 3 kg/potlift, *par5* = 250 t, *par6* = 50 and *par7* = 180. A different rule, with *par5* = 260 t, was proposed by industry in October.

Initially, only the industry rule as proposed was evaluated. After presentations and early discussions, including with the NRLMG, industry requested that a few other members of this family be evaluated.

Most of the rules evaluated were "plateau step" rules of the form illustrated in Figure 44. They are defined as follows:

par1	rule type (in this case, 4)
par2	CPUE at which TACC becomes zero (kg/potlift)
par3	CPUE corresponding with left edge of plateau (kg/potlift)
par4	CPUE corresponding with right edge of plateau (kg/potlift)
par5	TACC while CPUE is on the plateau (t)
par6	width of steps above the plateau (kg/potlift)
par7	step height (as a proportion of preceding TACC)
par8	minimum TACC change threshold (as a proportion of preceding TACC)

Provisional TACC (before operation of buffering rules) is given by:

$$TACC_{y+1} = 0 \quad \text{for } I_y \le par2$$

$$TACC_{y+1} = par5\left(\frac{I_y - par2}{par3 - par2}\right) \quad \text{for } par2 < I_y \le par3$$

$$TACC_{y+1} = par5 \quad \text{for } par3 < I_y \le par4$$

$$TACC_{y+1} = par5\left((1 + par7)^{\text{floor}\left((I_y - par4)/par6\right)+1}\right) \quad \text{for } I_y > par4$$

The rules that were evaluated were developed in several ways:

- by trying to mimic the industry-proposed rule
- by iteratively adjusting promising rules to improve performance of one or more indicators
- by running large sets of rules with several parameters set at a range of levels in a "shotgun" approach".

In all, about 1000 harvest rules were evaluated. Because the industry had proposed a TACC reduction through their proposed rule, nearly all the rules evaluated had a plateau height of 250 t; only very late in the exercise did it become obvious that industry had decided to try to retain the TACC of 260 t and that rules with higher plateau height should be evaluated.

In the past, rules have been evaluated with a maximum change threshold and/or a "latent year" that prevented two successive TACC changes. These two options were not explored in the work described here; they were considered unnecessary when stability is imparted by having a plateau rule.

4.3 Performance indicators

Performance was evaluated over 20 years in each of 1000 simulations for each of the two base cases for each rule evaluated. For biomass, catch and CPUE indicators, the mean (over 20 years) was calculated for each simulation, and the indicator was reported as the median and the 5th and 95th quantiles of the posterior distribution of the 1000 means. Average annual change in TACC was treated similarly, where the percentage of changes was calculated as the change divided by the mean TACC:

$$AAVH = \frac{\sum_{y=2015}^{y=2034} 100 \frac{\left|TACC_y - TACC_{y-1}\right|}{0.5\left(TACC_y + TACC_{y-1}\right)}}{20}$$

Terminal biomass was reported as the median of the posterior distribution of biomass in the last projection year. Minimum commercial and recreational catches were reported as the posterior distribution of the minimum catches during each simulation; similarly minimum CPUE. The 5-year commercial catch was reported as the median of the posterior distribution of commercial catch in the 5th projection year.

Probabilities that biomass was less than a reference level, or that CPUE was less than or greater then a particular value, and the number of TACC changes during simulations, were reported as the mean values.

The complete list of indicators that were output was:

- average biomass (scaled by *Bref*)
- terminal biomass (scaled by *Bref*)
- minimum commercial catch
- average commercial catch
- average 5-year commercial catch
- minimum recreational catch
- average recreational catch
- minimum CPUE
- average CPUE
- AAVH, the average percentage change in TACC
- number of changes in TACC
- average vulnerable biomass/*Bmsy*
- probability that biomass was less than *Bref*
- probability that biomass was less than *Bmin*
- probability that biomass was less than *Bmsy*
- probability that *SSB* was less than 20% *SSB0*
- probability that *SSB* was less than 10% *SSB0*
- probability that biomass was less than 50% *Bref*
- probability that biomass was less than 25% *Bref*
- probability that CPUE was below the left of the plateau
- probability that CPUE was above the right of the plateau
- probability that AW CPUE was greater than 1.14
- probability that AW CPUE was greater than 1.5
- minimum CPUE before observation error was applied
- average CPUE before observation error was applied
- total biomass in projection year
- total biomass in projection year divided by *B0*
- total numbers in projection year
- total biomass in projection year divided by *N0*

The total output from each rule was 150 indicator values. Not all of these were considered useful; for instance, 5th and 95th quantiles were not discussed by the RLFAWG; total biomass and numbers were not compared. The NRLMG agreed on a final list of key indicators to be shown to stakeholders.

4.4 Productivity of the operating model

Productivity was explored with a large set of plateau step rules. The set was deliberately constructed so that some rules would be very conservative and others aggressive (with low and high fishing intensity respectively). As average[2] commercial catch increases, average CPUE decreases (Figure 45). The two base cases had different forms of this relation: in the fixed *Gshape* base case average CPUE decreased with increasing catch at a slower rate than in the fixed *GCV* base case. The two relations were the same when average catch is about 240 t, with average CPUE of 1.4 kg/potlift.

Minimum commercial catch (Figure 46) was not such a simple function of average commercial catch: for a given level of average commercial catch there was wide variation in minimum catch. This indicator was thus a key one when rules were compared.

The probability that CPUE was greater than 1.14 kg/potlift, previously but not this year used as a reference point, decreased with increasing commercial catch (Figure 47). Again, rules tested under the two base case operating models showed different relations. The fixed *GCV* base case suggested that this probability remained high until an average catch of 150 t, then decreased to reach 50% at 230 t. The fixed *Gshape* base case suggested that the probability declined when average catch exceeded 125 t, but declined less steeply. Again, the two relations crossed when average catch was near 250 t, with probability 38%. The probability that CPUE was 1.5 kg/potlift or higher showed a similar form (Figure 48).

Because recreational catch was assumed to be taken with a constant exploitation rate, it declined with declining abundance or with increasing average commercial catch (Figure 49). The relation was not 1:1. Under the fixed *Gshape* base case, as average commercial catch varied from 100 t to 250 t, average recreational catch declined from 22 t to 15 t. Thus, a change of 200 t in commercial catch translated to a change of 7 t in recreational catch. Under the fixed *GCV* base case, the comparable change in average recreational catch was from 27 t to 12 t, or 15 t.

4.5 Minimum change threshold

One rule was used to explore the effect of the minimum change threshold using both alternative base cases (Table 12). There was almost no effect on catch and CPUE indicators except that minimum CPUE decreased slightly. The main effect was on the proportion of years with a TACC change, which decreased from 87% with a no threshold to 57% with a 5% threshold under the fixed GCV model, and similarly in the other model. Average annual change also decreased but much less dramatically.

[2] the summarised indicator value for one rule, i.e. the median of the posterior distribution of the mean values across the 20 years of a run

4.6 Screening

After initial explorations, we removed rules with poor performance relative to other rules. Presentation to the last RLFAWG and the first NRLMG meeting involved 115 rules. The screening criteria removed rules:

- that, using the 2013–14 CPUE of 2.2 kg/potlift, would produce a TACC of less than 230 t
- that produced average commercial catch less than 210 t
- that produced average commercial catch greater than 240 t
- that produced average CPUE less than 1.3
- that produced average CPUE greater than 1.7
- that produced low average minimum catch

4.7 Utility function approach

For the first time, we experimented with evaluation of the rules using a utility function. We used a multiplicative utility function so that the utility score would be zero when any of the separate components was zero (see Bentley et al. 2003b). We used the components:

- average catch
- average CPUE
- the probability that biomass was less than *Bmin*, P(B<*Bmin*)
- the probability that biomass was less than *Bmsy*, P(B<*Bmsy*)
- the proportion of years with TACC change

The utility functions for P(B<*Bmin*) and P(B<*Bmsy*) were simply 1 when P was less than 0.05, then zero for higher P values. This was a nominal exercise, because all the rules had P values for these two indicators less than 0.05 and thus a utility of 1 for these components.

The utility function for CPUE was zero for values less than 0.5 kg/potlift, 1 for values higher than 2 kg/potlift, and linear in between (Figure 50); this was arbitrary but was discussed with a CRA 3 industry member.

The function for average commercial catch is shown in Figure 51; this was partly arbitrary and partly based on the history of the fishery and the productivity estimates described above. The function for proportion of years with change is shown in Figure 52; this was arbitrary.

When 114 screened rules were scored (scores from the two alternative base cases were averaged) and then ranked, the rank was only loosely related to average commercial catch (Figure 53) and mostly unrelated to average CPUE (Figure 54). The rank proved to be highly correlated with the proportion of years with change (Figure 55). Utility scoring was not pursued further.

4.8 Robustness trials

We made four robustness trials with each of the two base case models. Each of the final set of 115 rules presented to the NRLMG was thus evaluated with ten separate operating models: the base case plus four robustness trials for each of the two alternative base cases. The four trials were:

R1 arbitrarily reduced recruitment
R2 with CPUE observation error doubled
R3 with the one-epoch growth estimates described above
R4 with *M* fixed to 0.12

The R1 and R2 trials used the base case McMC results and changed recruitment or observation error in projections. For R1, we examined the 10-year mean of median *Rdev*s for each 10-year period from 1979–88 to 2002–11, and we used the smallest value as the mean of projected *Rdev*s (-0.136 for the fixed *GCV* base case and -0.229 for the fixed *Gshape* base case). For the R3 and R4 trials we used the McMC results from the McMC sensitivity trials described above.

4.9 Rule viewer

So that stakeholders could view and compare the rules easily, a viewer was constructed in Excel. The evaluation output lines for each rule in all trials were loaded onto one line of a large matrix. The user could specify the rule (line number) to be viewed, and the Excel viewer used a lookup procedure to:

- find the rule parameters and plot the rule
- give base case and R1 results for several key indicators
- give average results from the two alternative base cases for the other robustness trials
- show the TACC that would be produced by that rule for 2015–16.

The viewer output for one rule is shown in Figure 56. This was one of two harvest control rules taken forward to consultation by the NRLMG; the other is shown in Figure 57.

The results in these two figures show that the fixed *GCV* operating model gave more optimistic results than the fixed *Gshape* model, reflected in higher average commercial catch, higher average CPUE, more years with CPUE higher than a reference level, and less response in robustness trial R1. Apart from a large difference in the proportion of years with TACC change, the two operating models gave similar results for each of the two rules. In the robustness trials, R1 with reduced recruitment had the most pronounced effects. R2 with increased observation error increased the frequency and scale of TACC change and decreased the average minimum CPUE and hence average minimum commercial catch, but had small effects on other indicators.

5. DISCUSSION

The MSLM model fit the CRA 3 data more easily than in previous CRA 3 stock assessments. Problems included difficulty in finding runs that were pdH, relatively high estimated *M* values, trouble estimating the size at maximum selectivity, requiring a prior to obtain plausible values, sensitivity to growth approaches that led to two alternative base cases. The high *M* probably reflects a mis-specification of some kind; it could possibly alias for unknown migration.

Other major uncertainties include the low proportion of mature females and growth patterns. The earliest catch samples showed a proportion of mature females that was comparable with males, but after 1990 the proportion fell to low values not seen in other stocks. The possible explanations could be low vulnerability of mature females, high mortality or emigration. Emigration is not supported by tag-recapture patterns (Kendrick & Bentley 2003).

Uncertainty in growth remains a problem despite the large number of records available. Most of the male fish were tagged at sizes below MLS, and recent female recaptures are scarce. Our analysis suggests that growth has varied over time, and was low from 1996 until recently, when it may have increased again. The model attempted to address the disparity in growth before and after 1996, but further refinement would be necessary to capture any more complex patterns. It seems likely that growth can vary in response to environmental factors, density and factors that are different in protected areas (Freeman et al. 2012). Variation in growth is an example of non-stationary dynamics that cause uncertainty in this kind of modelling. Punt et al. (2013b) showed in a simulation study for Victorian lobsters that changes in *M* and growth over time do not affect the ability of the Victorian management procedure to achieve sustainability goals.

The difference in results between the two alternative base cases was surprising. It was not possible for the model to estimate both *GCV* and *Gshape*, and fixing one or the other gave different biomass estimates and recruitment trajectories.

The MPD sensitivity trials that involved removing datasets one at a time showed that the CR dataset had little influence on the results, and that the tag and LF data sets were important. They also showed a high level of redundancy in the data: for instance, without the tag data set the growth estimates were not strikingly different from the base case. Early biomass was quite sensitive to data set removals, but later biomass was not (see Figure 23). Without the LF data, *M* went to its upper bound.

Both MPD and McMC sensitivity trials suggested that the stock assessment results were robust to modelling choices. Some may seem to be major decisions but their effects on the conclusions about state of the stock were relatively small.

As always, the RLFAWG identified the lack of information on non-commercial catches and their trends as being a major source of uncertainty. Illegal catches especially are poorly known. The recent large-scale multi-species recreational survey made recreational catch estimates for CRA 3, but the charter fleet was not included and the nature of the CRA 3 fishery suggests great uncertainty around the estimate.

Our assumption that recreational catch is proportional to abundance is controversial. The recreational fishery is partly constrained by the bag limit, but daily catches are commonly less than the bag limit and bags can be easily distributed across participants, so bag limits are only a weak constraint, and both fishers and fishing trips can increase as abundance increases. Assuming that catch is proportional to abundance implies constant effort, but it is possible that recreational effort may be increasing over time because of increasing interest; if this is true, catch may be increasing faster than abundance. In any case, the effects of changing the illegal and recreational catch assumptions on these stock assessment conclusions were predictable but relatively small.

This stock assessment suggests no sustainability concerns for CRA 3. The short-term projections suggest that the stock will decline but still remain well above the reference levels *Bmin* and *Bmsy*. There is no explicit target for CRA 3, and stakeholders most likely would want the stock to be well above these levels.

It was surprising that the puerulus index did not pass the randomisation trial: the null hypothesis could not be rejected. The null hypothesis was strongly rejected in both CRA 5 and CRA 4 (Haist et al. 2011; Breen et al. 2012). The index is not from a consistent set of collector groups, but rather from several groups that overlap in time; standardisation should produce a consistent index. The RLFAWG made changes to NIWA's default standardisation protocols that should have improved the quality of the index. However, when the model was fit experimentally to puerulus indices, the results were not very different from the base cases where puerulus was not fit. If there were a signal in the puerulus data, the main benefit would be in the short-term predictions. In other words, it would be of more benefit to an assessment/prediction paradigm than to the management procedure-based regime (see Bentley & Stokes 2009). The variable and uncertain New Zealand experience with puerulus settlement indices stands in contrast to the Western Australian experience (e.g. Caputi et al. 2014).

The operating models constructed from the two base cases gave somewhat different rule results when a wide range of fishing intensity was explored. At the time of writing, the NRLMG has gone to consultation on rules 4 and 6. Although the two model results differed for these specific rules, performance was acceptable for both rules. Average commercial and recreational catches showed the usual trade-off, but the change in average recreational catch between rules was small compared with the change in average commercial catch; the trade-off pattern was different between the two operating models.

The final industry-proposed rule (rule 4) performed reasonably well: it was very safe in the base case and appeared to represent an acceptable balance between average catch and average abundance. Although it would change TACC more often than rule 6, CRA 3 industry supported this because they believed it was more responsive than rule 6 when CPUE was between 1.25 and 2.00 kg/potlift; whereas rule 6 had a single TACC value across this range of CPUE.

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Table 1: Fixed quantities in the two alternative CRA 3 base cases.

Quantity	Description	Value	Notes
	mean of prior on *M*	0.12	
	std. dev. of *M* prior	0.16	
	mean of prior on *SelMaxM*	52.0	
	mean of prior on *SelMaxF*	60.0	
	std. dev. of *SelMax* priors	6–10	
initER	initial exploitation rate	0.0	
sigmaR	*Rdev* std. dev.	0.4	
CPUEpow	CPUE shape	1.0	sensitivity trial
mat50	size at 50% maturation	41.25	
mat95-mat50	shape	11.83	
Gshape	shape of growth curve	5.0	in fixed *Gshape* base
GCVM	variability of growth	0.5	in fixed *GCV* base
GCVF	variability of growth	1.0	in fixed *GCV* base
GDD	density-dependence of growth	0.0	sensitivity trial
Gmin	minimum growth std. dev.	1.0	
Gobs	growth obs. error	1.0	in fixed *Gshape* base
Gobs	growth obs. error	1.5	in fixed GCV base
VR	right-hand limb of selectivity	200	
	mean size at recruitment	32.0	
	std. dev. of recruitment size	2.0	
sigmaCR	std. dev. for CR	0.3	
N-R	Newton-Raphson iterations	4	in fixed *Gshape* base
N-R	Newton-Raphson iterations	5	in fixed *GCV* base
	handling mortality	0.1	
aM	length-weight intercept	4.16E-06	
aF	length-weight intercept	1.30E-05	
bM	length-weight exponent	2.9354	
bF	length-weight exponent	2.5452	
	minimum survival	0.2	

Table 2: For estimated parameters, the estimation phases, lower and upper bounds, prior type (0=uniform, 1 = normal, 2 = lognormal), prior mean and standard deviation (n.a. = not applicable), and initial values for the fixed *GCV* base case (upper half) and fixed *Gshape* base case (lower half).

Selectivity epoch	Growth epoch		Phase	Lower bound	Upper bound	Prior type	Prior mean	Prior std	Initial value
		ln(*R0*)	1	1	25	0	0	0	20
		M	4	0.01	0.35	2	0.12	0.4	0.16
		Rdev	2	-2.3	2.3	1	0	0.4	0
		ln(q*CPUE*)	1	-25	0	0	n.a.	n.a.	-6
		ln(*qCR*)	1	-25	2	0	n.a.	n.a.	-3.4
	1945–91	*Galpha*	2	1	20	0	n.a.	n.a.	3
	1945–91	*Gdiff*	2	0.001	1	0	n.a.	n.a.	0.7
	1945–91	*Gshape*	3	0.1	15	0	n.a.	n.a.	8
	1945–91	*GCV*	fixed	0.01	5	0	n.a.	n.a.	0.5
	1995–2013	*Galpha*	2	1	20	0	n.a.	n.a.	7.5
	1995–2013	*Gdiff*	2	0.001	1	0	n.a.	n.a.	0.12
	1995–2013	*Gshape*	3	0.1	15	0	n.a.	n.a.	8
	1995–2013	*GCV*	fixed	0.01	2	0	n.a.	n.a.	1
epoch 1		*Sel_L*	4	1	50	0	n.a.	n.a.	6
epoch 2		*Sel_L*	4	1	50	0	n.a.	n.a.	6
epoch 1		*Sel_R*	5	30	70	1	52	4	52
epoch 2		*Sel_R*	5	30	70	1	60	4	60
	males AW	*Vuln1*	3	0.01	1	0	n.a.	n.a.	0.9
	immat AW	*Vuln2*	3	0.01	1	0	n.a.	n.a.	0.1
	all females SS	*Vuln3*	3	0.01	1	0	n.a.	n.a.	0.4
	mature AW	*Vuln4*	3	0.01	1	0	n.a.	n.a.	0.1
		ln(*R0*)	1	1	25	0	0	0	20
		M	4	0.01	0.35	2	0.12	0.4	0.16
		Rdev	2	-2.3	2.3	1	0	0.4	0
		ln(q*CPUE*)	1	-25	0	0	n.a.	n.a.	-6
		ln(*qCR*)	1	-25	2	0	n.a.	n.a.	-3.4
	1945–91	*Galpha*	2	1	20	0	n.a.	n.a.	3
	1945–91	*Gdiff*	2	0.001	1	0	n.a.	n.a.	0.7
	1945–91	*Gshape*	fixed	0.1	15	0	n.a.	n.a.	5
	1945–91	*GCV*	3	0.01	5	0	n.a.	n.a.	0.405
	1995–2013	*Galpha*	2	1	20	0	n.a.	n.a.	7.5
	1995–2013	*Gdiff*	2	0.001	1	0	n.a.	n.a.	0.12
	1995–2013	*Gshape*	fixed	0.1	15	0	n.a.	n.a.	5
	1995–2013	*GCV*	3	0.01	5	0	n.a.	n.a.	0.92
epoch 1		*Sel_L*	4	1	50	0	n.a.	n.a.	6
epoch 2		*Sel_L*	4	1	50	0	n.a.	n.a.	6
epoch 1		*SelMax*	4	30	90	1	52	10	55
epoch 2		*SelMax*	4	30	90	1	60	6	65
	males AW	*Vuln1*	3	0.01	1	0	n.a.	n.a.	0.8
	immat AW	*Vuln2*	3	0.01	1	0	n.a.	n.a.	0.8
	all females SS	*Vuln3*	3	0.01	1	0	n.a.	n.a.	0.8
	mature AW	*Vuln4*	3	0.01	1	0	n.a.	n.a.	0.8

Table 3: Comparison of fitting inputs and results from the two base cases. The first section shows dataset weights and the resulting fit diagnostics; the next section shows function values; the next section shows parameter values (for growth, M indicates male and F female and the suffix numeral indicates which growth epoch; for selectivity the numeral indicates the selectivity epoch); the final section shows some derived parameters and the deterministic time from 30 mm TW to recruitment at 52 mm for males and 60 mm for females from the two growth epochs. Grey cells contain fixed values.

Quantity	Fixed *GCV*	Fixed *Gshape*
LFs-weight-male	1.92	1.25
LFs-weight-imm	0.18	0.16
LFs-weight-female	0.7	0.68
LFs-sdnr	0.34	0.87
LFs-MAR	0.151	0.169
LFs-LL	4565.1	3861.5
Tags-weight	1.25	0.88
Tags-sdnr	1.36	1.303
Tags-MAR	0.67	0.656
Tags-LL	5109	5136.4
CPUE-weight	1.4	1.2
CPUE-sdnr	1.086	0.947
CPUE-MAR	0.625	0.628
CPUE-LL	-76.9	-76
CR-weight	3	2
CR-sdnr	0.996	0.696
CR-MAR	0.718	0.219
CR-LL	-19.9	-18.2
SexRatio-weight	7.2	7
SexRatio-sdnr	1.357	1.326
SexRatio-MAR	0.724	0.705
total_Priors	-31.3	-23.5
function value	9546.0	8880.2
ln(R0)	13.95	14.66
M	0.219	0.245
ln(qCPUE)	-5.277	-6.197
ln(qCR)	-2.989	-3.446
GalphaM1	4.314	4.345
GbetaM1	4.127	3.397
GdiffM1	0.957	0.782
GshapeM1	6.822	5
GCVM1	0.5	0.351
GalphaF1	1.602	2.181
GbetaF1	1.317	0.002
GdiffF1	0.822	0.001
GshapeF1	12.82	5
GCVF1	1	0.844
GalphaM2	2.187	2.349
GbetaM2	1.504	0.808
GdiffM2	0.688	0.344
GshapeM2	13.669	5
GCVM2	0.5	0.459
GalphaF2	2.406	1.858
GbetaF2	0.002	0.002
GdiffF2	0.001	0.001
GshapeF2	5.598	5
GCVF2	1	1.394
Vuln1	0.941	0.887
Vuln2	0.028	0.046
Vuln3	0.19	0.321
Vuln4	0.058	0.089
Sel_L1M	6.82	4.73
Sel_max1M	57.52	54.71
Sel_L1F	9.33	7.9

Quantity	Fixed *GCV*	Fixed *Gshape*
Sel_max1F	60.48	60.83
Sel_L2M	8.04	5.4
Sel_max2M	57.49	55.33
Sel_L2F	11.68	12.17
Sel_max2F	63.33	67.37
Bmsy	182.1	202.4
B2014/Bmsy	3.166	4.462
MSY	245	217.6
Fmult	5.85	7.25
Male_yrs to MLS1	2.5	3.5
Female_yrs to MLS1	8	10
Male_yrs to MLS2	2.5	4.5
Female_yrs to MLS2	8	10

Table 4: Comparing parameter estimates from the fixed *Gshape* base case and the same model fit to the puerulus indices.

Quantity	Base	Puerulus
total_Priors	-23.5	-22.5
function value	8880.2	8884.19
ln(R0)	14.66	14.65
M	0.245	0.248
ln(qCPUE)	-6.197	-6.152
ln(qCR)	-3.446	-3.404
GalphaM1	4.345	4.347
GbetaM1	3.397	3.416
GCVM1	0.351	0.351
GalphaF1	2.181	2.177
GbetaF1	0.002	0.002
GCVF1	0.844	0.845
GalphaM2	2.349	2.358
GbetaM2	0.808	0.782
GCVM2	0.459	0.451
GalphaF2	1.858	1.780
GbetaF2	0.002	0.002
GCVF2	1.394	1.430
Vuln1	0.887	0.878
Vuln2	0.046	0.062
Vuln3	0.321	0.425
Vuln4	0.089	0.115
Sel_L1M	4.73	5.40
Sel_max1M	54.71	56.47
Sel_L1F	7.90	10.81
Sel_max1F	60.83	68.04
Sel_L2M	5.40	5.42
Sel_max2M	55.33	55.36
Sel_L2F	12.17	12.92
Sel_max2F	67.37	70.45
Bmsy	202.4	201.3
B2014/Bmsy	4.462	4.180
MSY	217.6	212.1
Fmult	7.25	6.64
yrstoMLSM1	3.5	3.5
yrstoMLSF1	10	10
yrstoMLSM2	4.5	4.5
yrstoMLSMF2	10	10

Table 5: Results of puerulus randomisation trials; the two columns on the left show the probability of obtaining a fit as good as or better than the fit to the real data, and the two columns on the right show simple correlations between MPD recruitment and the puerulus index at the lags shown.

	p-value		Simple correlation	
Lag	Fixed *GShape*	Fixed *GCV*	Fixed *GShape*	Fixed *GCV*
0	0.656	0.219	0.034	0.326
1	0.809	0.346	0.353	0.174
2	0.704	0.168	0.406	0.099
3	0.315	0.281	0.264	0.095
4	0.100	0.191	0.057	0.318
5	0.058	0.453	0.004	0.195
6	0.081	-	-0.036	0.255
7	0.097	-	-0.195	-0.089

Table 6: Summary of MPD sensitivity trials for the fixed *GCV* base case. Grey cells indicate fixed quantities; boxed yellow cells indicate values that are substantially different from others in the row.

	base	**sens1 double rec**	sens2 half illegal	sens3 double illegal	sens4 no CPUE	sens5 no LFs	sens6 no CR	sens7 no tags	sens8 fixed M	sens9 d-d growth	sens10 no LF trunc	sens11 CPUE pow	sens12 N-R 3	sens12a N-R 4	sens13 log. sel.
pdh?	yes	**no**	yes	no	yes	yes	no	yes	no	yes	yes	no	no	yes	yes
LFs-sdnr	0.340	**0.341**	0.349	0.338	0.342	1.47E+11	0.339	0.848	0.883	0.340	0.519	0.342	0.341	0.340	0.339
LFs-MAR	0.151	**0.150**	0.153	0.150	0.148	0.487	0.151	0.147	0.163	0.151	0.175	0.152	0.151	0.151	0.151
LFs-LL	4565.1	**4566.5**	4569.7	4562.3	4545.0	13677.3	4564.5	4551.3	4563.8	4565.1	9913.3	4567.2	4564.7	4564.9	4571.0
Tags-sdnr	1.360	**1.360**	1.363	1.358	1.344	1.337	1.360	1.617	1.387	1.360	1.367	1.359	1.361	1.360	1.360
Tags-MAR	0.670	**0.670**	0.671	0.667	0.668	0.658	0.669	0.684	0.673	0.670	0.667	0.669	0.669	0.669	0.669
Tags-LL	5109.0	**5109.1**	5110.4	5108.4	5100.3	5089.4	5108.9	5815.1	5117.5	5109.0	5116.9	5106.2	5109.5	5109.1	5109.0
CPUE-sdnr	1.086	**1.083**	1.043	1.126	4.335	0.600	1.060	0.780	1.011	1.086	1.235	1.102	1.063	1.079	1.067
CPUE-MAR	0.625	**0.640**	0.619	0.648	5.234	0.441	0.622	0.483	0.764	0.625	0.721	0.614	0.637	0.627	0.730
CPUE-LL	-76.9	**-77.1**	-80.1	-73.8	945.2	-105.6	-78.8	-96.9	-82.4	-76.9	-64.8	-75.7	-78.6	-77.4	-78.3
CR-sdnr	0.996	**0.995**	0.995	0.993	1.111	0.968	1.620	0.756	1.096	0.996	1.001	0.990	1.002	0.997	0.996
CR-MAR	0.718	**0.711**	0.718	0.706	0.350	0.535	6.169	0.448	0.842	0.718	0.738	0.697	0.741	0.724	0.722
CR-LL	-19.9	**-19.9**	-19.9	-19.9	-18.5	-20.2	162.5	-22.2	-18.7	-19.9	-19.8	-19.9	-19.8	-19.8	-19.9
Sex-sdnr	1.357	**1.360**	1.373	1.345	1.321	26.701	1.362	1.327	1.401	1.357	1.550	1.369	1.363	1.359	1.367
Sex-MAR	0.724	**0.737**	0.731	0.740	0.606	17.306	0.722	0.544	0.659	0.724	0.712	0.757	0.717	0.720	0.726
Priors	-31.3	**-31.4**	-31.3	-31.3	-50.7	-44.9	-29.6	-37.7	-8.0	-31.3	-27.6	-33.0	-31.0	-31.2	-34.5
LL	9546.0	**9547.1**	9548.8	9545.7	9576.2	4918.8	9565.0	4394.5	9572.2	9546.0	14918.0	9544.8	9544.7	9545.6	9547.3
ln(*R0*)	13.95	**13.97**	14.13	13.85	13.88	14.55	13.92	14.28	13.46	13.95	13.92	13.96	13.92	13.94	13.94
M	0.219	**0.219**	0.222	0.217	0.180	0.327	0.215	0.288	0.12*	0.219	0.207	0.220	0.217	0.218	0.216
ln(*qCPUE*)	-5.277	**-5.288**	-5.173	-5.351	-6*	-5.735	-5.156	-5.357	-4.486	-5.277	-5.152	-4.573	-5.128	-5.237	-5.295
ln(*qCR*)	-2.989	**-2.997**	-3.098	-2.936	-3.608	-2.656	-3.4*	-2.375	-3.272	-2.989	-2.961	-2.991	-2.955	-2.980	-3.017
CPUEpow	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	0.865	1*	1*	1*
GalphaM1	4.314	**4.314**	4.344	4.292	4.319	4.315	4.319	1.672	4.510	4.314	4.362	4.315	4.325	4.316	4.314
GbetaM1	4.127	**4.132**	3.799	4.292	3.904	4.132	4.106	0.002	0.949	4.127	3.430	4.021	4.054	4.108	4.121
GshapeM1	6.822	**6.828**	5.994	7.341	6.036	6.498	6.756	15.000	2.015	6.822	5.193	6.530	6.624	6.770	6.824
GalphaF1	1.602	**1.601**	1.609	1.596	1.647	1.690	1.602	1.000	1.544	1.602	1.613	1.581	1.605	1.603	1.593
GbetaF1	1.317	**1.315**	1.300	1.330	1.424	1.440	1.318	0.001	1.227	1.317	1.295	1.359	1.308	1.314	1.307
GshapeF1	12.820	**12.801**	12.585	13.025	15.000	15.000	12.817	10.781	12.837	12.820	12.469	13.635	12.683	12.772	12.841
GalphaM2	2.187	**2.186**	2.189	2.186	2.194	2.180	2.186	2.252	2.188	2.187	2.194	2.192	2.187	2.187	2.205
GbetaM2	1.504	**1.530**	1.462	1.517	1.463	1.600	1.525	0.002	1.695	1.504	1.373	1.484	1.523	1.509	1.443
GshapeM2	13.669	**13.803**	13.286	13.838	13.536	15.000	13.776	10.678	15.000	13.669	12.941	13.465	13.772	13.701	13.550
GalphaF2	2.406	**2.411**	2.435	2.387	2.097	1.000	2.406	3.007	2.018	2.406	2.485	2.401	2.407	2.406	2.420
GbetaF2	0.002	**0.002**	0.002	0.002	0.174	0.541	0.002	0.334	0.002	0.002	0.002	0.002	0.002	0.002	0.002

	base	**sens1 double rec**	sens2 half illegal	sens3 double illegal	sens4 no CPUE	sens5 no LFs	sens6 no CR	sens7 no tags	sens8 fixed M	sens9 d-d growth	sens10 no LF trunc	sens11 CPUE pow	sens12 N-R 3	sens12a N-R 4	sens13 log. sel.
GshapeF2	5.598	**5.629**	5.639	5.542	5.360	7.982	5.638	1.361	6.297	5.598	4.450	5.634	5.616	5.604	5.787
GDD1	0*	**0***	0*	0*	0*	0*	0*	0*	0*	0.000	0*	0*	0*	0*	0*
GDD2	0*	**0***	0*	0*	0*	0*	0*	0*	0*	0.000	0*	0*	0*	0*	0*
Vuln1	0.941	**0.934**	0.953	0.938	1.000	0.650	0.930	0.757	0.969	0.941	0.955	0.940	0.932	0.938	0.962
Vuln2	0.028	**0.027**	0.020	0.037	0.051	1.000	0.024	0.202	0.010	0.028	0.039	0.028	0.024	0.027	0.024
Vuln3	0.190	**0.188**	0.140	0.231	0.256	0.114	0.166	1.000	0.048	0.190	0.222	0.194	0.167	0.184	0.176
Vuln4	0.058	**0.057**	0.043	0.070	0.076	0.010	0.050	0.229	0.014	0.058	0.073	0.059	0.050	0.056	0.054
VL1M	6.82	**6.74**	6.64	6.91	6.55	2.82	6.92	6.02	6.76	6.82	7.98	7.20	6.72	6.78	50.00
Sel_L1M	57.52	**57.33**	58.65	56.62	55.74	51.51	57.92	53.31	60.05	57.52	62.09	58.58	57.42	57.47	
Sel_max1M	9.33	**9.21**	9.16	9.36	8.29	1.00	9.18	8.26	9.26	9.33	11.48	10.27	8.69	9.22	50.00
Sel_L1F	60.48	**60.16**	60.41	60.36	58.50	59.28	59.98	63.49	57.29	60.48	68.32	62.78	59.06	60.19	
Sel_max1F	8.04	**8.09**	8.47	7.73	8.67	50.00	8.30	7.02	10.35	8.04	7.90	7.95	8.34	8.12	49.08
Sel_L2M	57.49	**57.59**	59.36	56.30	59.06	52.45	58.25	55.15	63.67	57.49	57.91	57.40	58.40	57.72	
Sel_max2M	11.68	**11.69**	11.65	11.71	12.92	1.00	11.65	9.02	11.02	11.68	11.33	11.74	11.66	11.68	50.00
Sel_L2F	63.33	**63.28**	63.01	63.68	70.00	59.13	63.00	65.10	59.19	63.33	66.50	63.47	63.15	63.30	
Bmsy	182.1	**183.4**	157.1	199.4	203.4	292.8	167.0	228.1	91.3	182.1	180.4	185.0	166.8	178.1	182.2
B2014/Bmsy	3.166	**3.174**	3.517	3.007	1.926	2.596	3.096	2.522	3.208	3.166	3.213	3.370	3.042	3.128	3.226
MSY	245.0	**254.4**	243.9	247.7	247.4	292.9	239.4	306.1	174.4	245.0	235.0	247.0	240.8	244.0	247.8
Fmult	5.85	**5.49**	7.91	5.1	2.97	4.36	5.67	5.25	4.24	5.85	5.09	6.28	5.61	5.78	6.09
yrstoMLSM1	2.5	**2.5**	2.5	2.5	2.5	2.5	2.5	2.5	3.5	2.5	3	2.5	2.5	2.5	2.5
yrstoMLSF1	8	**8**	8	8	7	6	8	0	9	8	8	8	8	8	8
yrstoMLSM2	2.5	**2.5**	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
yrstoMLSMF2	8	**8**	8	8	10	0	8	8	10	8	8	8	8	8	8

Table 7: Summary of MPD sensitivity trials for the fixed *Gshape* base case. Grey cells indicate fixed quantities; boxed yellow cells indicate values that are substantially different from others in the row.

	base	sens1 2x rec	sens2 half illegal	sens3 twice illegal	sens4 no CPUE	sens5 no LFs	sens6 no CR	sens7 no tags	sens8 fixed *M*	sens9 d-d growth	sens10 no LF trunc	sens11 *CPUE pow*	sens12 N-R 3	sens12a N-R 5	sens13 log. sel.
pdh?	yes	yes	yes	yes	yes	yes	yes	no	yes	no	no	yes	yes	yes	no
LFs-sdnr	0.870	0.836	0.919	0.902	0.475	6.1.E10	0.875	6.202	0.759	0.870	0.848	0.501	0.969	0.871	1.715
LFs-MAR	0.169	0.170	0.170	0.169	0.159	1.013	0.168	0.133	0.166	0.169	0.183	0.161	0.170	0.169	0.165
LFs-LL	3861.5	3861.9	3865.2	3860.0	3845.8	15421.2	3862.9	3823.6	3853.7	3861.5	8336.7	3861.3	3862.7	3861.5	3863.5
Tags-sdnr	1.303	1.303	1.305	1.303	1.300	1.302	1.304	1.418	1.300	1.303	1.305	1.312	1.304	1.303	1.303
Tags-MAR	0.656	0.656	0.657	0.657	0.653	0.657	0.657	0.580	0.652	0.656	0.660	0.657	0.657	0.656	0.658
Tags-LL	5136.4	5136.6	5136.2	5135.9	5130.4	5123.6	5135.4	5633.4	5133.6	5136.4	5139.6	5134.7	5135.8	5136.4	5135.9
CPUE-sdnr	0.947	0.952	0.920	0.959	3.372	0.612	0.950	0.700	1.056	0.947	1.105	0.892	0.931	0.947	0.869
CPUE-MAR	0.628	0.638	0.639	0.622	2.569	0.455	0.623	0.417	0.592	0.628	0.629	0.584	0.624	0.626	0.608
CPUE-LL	-76.0	-75.6	-77.8	-75.2	548.0	-94.3	-75.8	-90.2	-68.4	-76.0	-64.7	-79.5	-77.1	-76.0	-81.0
CR-sdnr	0.696	0.700	0.703	0.691	1.288	0.660	0.937	0.653	0.811	0.696	0.735	0.698	0.692	0.696	0.676
CR-MAR	0.219	0.235	0.225	0.225	0.820	0.437	1.198	0.394	0.560	0.220	0.321	0.219	0.207	0.220	0.249
CR-LL	-18.2	-18.2	-18.1	-18.2	-11.7	-18.5	-12.5	-18.5	-17.2	-18.2	-17.9	-18.2	-18.2	-18.2	-18.3
Sex-sdnr	1.326	1.327	1.338	1.322	1.337	18.298	1.333	1.303	1.296	1.326	1.590	1.353	1.332	1.326	1.347
Sex-MAR	0.705	0.708	0.695	0.701	0.603	7.354	0.689	0.619	0.634	0.704	0.628	0.692	0.684	0.704	0.635
Priors	-23.5	-23.1	-21.9	-24.1	-51.4	-36.9	-24.8	-33.9	17.9	-23.5	-19.7	-24.6	-23.3	-23.5	-30.8
LL	8880.2	8881.5	8883.6	8878.5	8913.1	4974.0	8897.7	3680.9	8919.6	8880.2	13374.1	8873.7	8880.0	8880.3	8869.3
ln(*R0*)	14.66	14.67	14.88	14.55	14.44	15.21	14.70	14.41	13.67	14.66	14.62	14.71	14.67	14.66	14.75
M	0.245	0.244	0.256	0.241	0.184	0.350	0.251	0.270	0.12*	0.245	0.230	0.252	0.248	0.245	0.260
ln(*qCPUE*)	-6.197	-6.228	-6.327	-6.122	-6*	-5.327	-6.224	-4.851	-6.239	-6.198	-6.386	-9.402	-6.171	-6.200	-6.032
ln(*qCR*)	-3.446	-3.468	-3.585	-3.358	-4.303	-2.762	-3.4*	-2.527	-3.809	-3.446	-3.594	-3.465	-3.422	-3.447	-3.325
CPUEpow	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1.480	1*	1*	1*
GalphaM1	4.345	4.344	4.341	4.347	4.374	4.358	4.344	3.777	4.275	4.345	4.342	4.349	4.345	4.345	4.336
gbetaM1	3.397	3.395	3.430	3.388	3.445	3.427	3.403	0.122	2.969	3.396	3.500	3.407	3.413	3.397	3.403
GCVM1	0.351	0.351	0.351	0.350	0.351	0.350	0.351	0.073	0.351	0.351	0.352	0.350	0.351	0.351	0.351
GalphaF1	2.181	2.179	2.175	2.184	2.225	2.250	2.177	2.645	2.183	2.181	2.186	2.113	2.174	2.182	2.180
GbetaF1	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002
GCVF1	0.844	0.844	0.844	0.845	0.838	0.834	0.845	0.698	0.852	0.844	0.849	0.841	0.845	0.844	0.846
GalphaM2	2.349	2.350	2.356	2.346	2.275	2.313	2.350	1.898	2.335	2.349	2.333	2.344	2.354	2.349	2.350
GbetaM2	0.808	0.808	0.778	0.807	0.717	0.002	0.779	0.002	0.642	0.807	1.041	0.645	0.807	0.806	0.892
GCVM2	0.459	0.459	0.451	0.452	0.463	0.445	0.451	1.554	0.454	0.459	0.451	0.454	0.458	0.459	0.458
GalphaF2	1.858	1.857	1.850	1.821	1.638	1.000	1.788	1.858	1.340	1.856	1.957	1.800	1.785	1.856	1.596
GbetaF2	0.002	0.002	0.002	0.002	0.002	0.405	0.002	1.217	0.001	0.002	0.102	0.009	0.002	0.002	0.157

	base	sens1 2x rec	sens2 half illegal	sens3 twice illegal	sens4 no CPUE	sens5 no LFs	sens6 no CR	sens7 no tags	sens8 fixed *M*	sens9 d-d growth	sens10 no LF trunc	sens11 *CPUE pow*	sens12 N-R 3	sens12a N-R 5	sens13 log. sel.
GCVF2	1.394	1.402	1.377	1.421	1.458	0.978	1.423	1.523	1.896	1.398	1.266	1.397	1.426	1.398	1.491
GDD1	0*	0*	0*	0*	0*	0*	0*	0*	0*	1.7E-12	0*	0*	0*	0*	0*
GDD2	0*	0*	0*	0*	0*	0*	0*	0*	0*	1.7E-12	0*	0*	0*	0*	0*
Vuln1	0.887	0.887	0.886	0.884	1.000	0.817	0.883	0.864	0.949	0.887	0.933	0.920	0.881	0.887	0.863
Vuln2	0.046	0.045	0.059	0.048	0.088	1.000	0.065	0.131	0.050	0.046	0.060	0.079	0.062	0.046	0.169
Vuln3	0.321	0.317	0.412	0.330	0.400	0.071	0.445	0.718	0.199	0.320	0.400	0.511	0.427	0.321	1.000
Vuln4	0.089	0.088	0.113	0.091	0.121	0.010	0.121	0.183	0.057	0.089	0.121	0.142	0.116	0.089	0.262
VL1M	4.73	4.69	5.31	4.75	4.70	9.52	5.19	8.95	5.13	4.73	4.55	5.11	5.29	4.73	53.73
Sel_L1M	54.71	54.63	56.52	54.56	53.38	69.18	55.97	64.04	55.15	54.71	54.32	55.42	56.21	54.73	
Sel_max1M	7.90	7.84	10.65	7.91	7.33	1.00	10.61	10.46	7.49	7.90	10.65	11.77	10.72	7.91	67.27
Sel_L1F	60.83	60.64	67.80	60.75	58.67	60.27	67.57	71.36	58.10	60.81	66.53	69.25	67.77	60.85	
Sel_max1F	5.40	5.41	5.35	5.42	5.28	1.03	5.35	6.14	5.42	5.40	4.98	5.40	5.39	5.40	50.28
Sel_L2M	55.33	55.33	55.36	55.29	54.82	55.00	55.21	56.77	54.38	55.33	54.54	55.05	55.32	55.32	
Sel_max2M	12.17	12.15	12.91	12.16	13.24	50.00	12.93	11.25	11.14	12.17	12.59	12.88	12.91	12.17	62.67
Sel_L2F	67.37	67.22	70.45	67.38	70.83	34.78	70.58	71.94	62.48	67.35	70.65	70.91	70.45	67.36	
B2014/Bref	0.89	0.89	0.88	0.90	0.24	0.59	0.85	0.72	0.76	0.89	0.99	0.90	0.89	0.89	0.83
Bref	1013.1	1034.7	1173.2	929.0	3322.3	812.2	1092.8	528.0	1232.9	1013.3	1191.6	1063.6	991.3	1015.0	961.0
Bmsy	202.4	208.2	202.2	205.9	286.2	130.2	212.4	196.4	177.4	202.3	221.1	233.9	204.4	202.8	198.8
B2014/Bmsy	4.462	4.422	5.099	4.063	2.733	3.682	4.361	1.943	5.299	4.465	5.330	4.071	4.323	4.465	4.008
MSY	217.6	225.2	214.2	220.1	228.2	300.1	221.1	284.9	124.3	217.6	216.4	226.4	215.0	218.0	211.7
Fmult	7.25	6.86	8.75	6.38	3.98	15.2	7.12	4.14	3.88	7.26	7.85	6.67	6.87	7.27	6.09
yrstoMLSM1	3.5	3.5	3.5	3.5	3.5	3.5	3.5	2.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
yrstoMLSF1	10	10	10	10	10	10	10	8	10	10	10	11	10	10	10
yrstoMLSM2	4.5	4.5	4.5	4.5	4.5	4.5	4.5	3.5	4.5	4.5	5.5	4.5	4.5	4.5	4.5
yrstoMLSMF2	10	10	10	10	12	0	10	10	13	10	10	10	10	10	12

Table 8: Comparison of parameters from the two base case McMCs; little grey cells are fixed quantities.

			Fixed *GCV*			Fixed *Gshape*		
Growth	Sex	Quantity	0.05	Median	0.95	0.05	Median	0.95
		function value	8768.7	8780.0	8791.8	8104.7	8115.2	8126.6
		ln(*R0*)	13.84	13.99	14.15	14.42	14.67	14.94
		M	0.201	0.226	0.253	0.218	0.251	0.291
		ln(*qCPUE*)	-5.843	-5.623	-5.371	-6.533	-6.304	-6.077
		ln(*qCR*)	-3.306	-3.087	-2.837	-3.770	-3.476	-3.185
period1	male	*Galpha*	4.181	4.323	4.475	4.192	4.332	4.461
period1	male	*GBeta*	2.815	3.764	4.267	2.867	3.379	3.884
period1	male	*Gshape*	4.439	6.139	7.305	5	5	5
period1	male	*GCV*	0.5	0.5	0.5	0.331	0.354	0.377
period1	female	*Galpha*	1.448	1.610	1.820	1.958	2.149	2.321
period1	female	*Gbeta*	1.034	1.287	1.488	0.035	0.234	0.351
period1	female	*Gshape*	10.600	12.548	14.501	5	5	5
period1	female	*GCV*	1	1	1	0.742	0.829	0.932
period2	male	*Galpha*	2.085	2.184	2.287	2.247	2.339	2.423
period2	male	*GBeta*	0.878	1.376	1.792	0.285	0.665	1.026
period2	male	*Gshape*	11.739	13.019	14.404	5	5	5
period2	male	*GCV*	0.5	0.5	0.5	0.405	0.455	0.499
period2	female	*Galpha*	2.192	2.361	2.535	1.435	1.730	2.052
period2	female	*Gbeta*	0.003	0.014	0.031	0.002	0.011	0.031
period2	female	*Gshape*	4.670	5.315	5.989	5	5	5
period2	female	*GCV*	1	1	1	1.181	1.449	1.816
		Vuln1	0.884	0.963	0.996	0.811	0.894	0.972
		Vuln2	0.027	0.058	0.109	0.049	0.107	0.206
		Vuln3	0.217	0.318	0.447	0.396	0.704	0.965
		Vuln4	0.065	0.098	0.141	0.109	0.189	0.275
epoch 1	male	*Sel_L*	5.368	7.460	10.226	4.311	7.340	11.056
epoch 1	male	*SelMax*	54.70	58.28	63.02	54.09	60.20	67.70
epoch 1	female	*Sel_L*	7.73	11.29	13.85	8.97	11.81	15.07
epoch 1	female	*SelMax*	58.88	66.40	69.58	66.14	72.61	79.18
epoch 2	male	*Sel_L*	6.25	7.44	8.72	4.76	5.38	6.16
epoch 2	male	*SelMax*	53.44	55.68	58.28	53.88	55.13	56.58
epoch 2	female	*Sel_L*	10.51	12.06	13.66	12.01	13.71	15.71
epoch 2	female	*SelMax*	62.36	66.01	69.30	68.63	74.47	79.53

Table 9: Comparison of indicators from the two base case McMCs.

	Fixed *GCV*			Fixed *Gshape*		
	5%	Median	95%	5%	Median	95%
Bmin	156.3	194.3	235.7	265.6	334.3	412.9
B2014	524.7	704.1	956.1	765.8	1001.2	1335.0
Bref	508.1	633.8	777.3	915.0	1134.7	1418.8
B2017	338.2	596.3	964.8	435.7	690.1	1065.9
Bmsy	173.8	212.8	252.4	173.0	211.7	261.6
MSY	210.2	242.6	282.0	177.1	212.4	253.0
Fmult	4.80	6.02	7.79	5.57	7.34	9.37
SSB2013	1104.9	1243.7	1405.3	2061.3	2389.7	2842.6
SSB2017	1035.2	1273.0	1576.9	1785.2	2241.2	2896.9
SSBmsy	771.5	880.8	1008.2	1351.9	1544.9	1786.7
CPUE2013	1.782	2.094	2.477	1.467	1.714	2.005
CPUE2017	0.774	1.662	2.799	0.609	1.003	1.517
CPUEmsy	0.233	0.288	0.351	0.156	0.196	0.241
B2014/Bmin	2.89	3.64	4.61	2.45	3.01	3.73
B2014/Bref	0.846	1.119	1.497	0.679	0.886	1.121
B2014/Bmsy	2.609	3.333	4.405	3.820	4.725	5.827
B2017/B2014	0.566	0.846	1.157	0.510	0.686	0.903
B2017/Bref	0.526	0.943	1.500	0.399	0.608	0.898
B2017/Bmsy	1.639	2.797	4.554	2.239	3.234	4.640
SSB2013/SSB0	0.619	0.697	0.804	0.930	1.068	1.254
SSB2017/SSB0	0.582	0.713	0.892	0.803	0.995	1.273
SSB2013/SSBmsy	1.247	1.410	1.610	1.357	1.549	1.800
SSB2017/SSBmsy	1.174	1.433	1.792	1.172	1.449	1.831
SSB2017/SSB2013	0.861	1.019	1.196	0.787	0.930	1.123
USL2013	0.188	0.238	0.305	0.123	0.157	0.202
USL2017	0.180	0.292	0.514	0.163	0.252	0.399
USL2017/USL2013	0.830	1.210	1.965	1.164	1.599	2.244
Btot2013	2485.0	2898.7	3438.1	4814.6	5821.1	7170.6
Btot2013/Btot0	0.417	0.495	0.593	0.560	0.672	0.809
Ntot2013	7400000	8950000	11200000	15200000	19200000	25000000
Ntot2013/Ntot0	0.627	0.756	0.948	0.744	0.909	1.137
P(B2014>Bmin)	1.00			1.00		
P(B2014>Bref)	0.75			0.19		
P(B2014>Bmsy)	1.00			1.00		
P(B2017>Bmin)	1.00			0.99		
P(B2017>Bref)	0.44			0.02		
P(B2017>Bmsy)	1.00			1.00		
P(B2017>B2014	0.21			0.02		
P(SSB2013>SSBmsy)	1.00			1.00		
P(SSB2017>SSBmsy)	1.00			1.00		
P(USL2017>USL2013	0.77			1.00		
P(SSB2013<0.2SSB0)	0.00			0.00		
P(SSB2017<0.2SSB0	0.00			0.00		
P(SSB2013<0.1SSB0)	0.00			0.00		
P(SSB2017<0.1SSB0)	0.00			0.00		

Table 10: Median parameter estimates in the McMC sensitivity trials; little grey cells indicate fixed quantities.

			Fixed *GCV*					Fixed *Gshape*				
Growth	Sex	Quantity	base	*M*= 0.12	*M* prior uniform	poo lag 2	one epoch	base	*M*= 0.12	M prior uniform	poo lag 2	one epoch
		fn value	8780.0	8809.3	8781.6	8781.9	9028.9	8115.2	8738.6	8114.6	8119.6	8873.7
		ln(*R0*)	13.99	13.43	14.06	13.95	14.00	14.67	13.62	14.75	14.66	14.40
		M	0.226	0.120	0.242	0.221	0.219	0.251	0.120	0.263	0.253	0.225
		ln(*qCPUE*)	-5.623	-5.380	-5.683	-5.562	-5.376	-6.304	-6.291	-6.272	-6.258	-5.949
		ln(*qCR*)	-3.087	-3.381	-3.060	-3.073	-2.902	-3.476	-3.780	-3.430	-3.438	-2.934
		ln(*qpoo*)	-6	-6	-6	-13.78	-6	-6	-6	-6	-14.64	-6
period1	male	*Galpha*	4.32	4.43	4.33	4.32	2.93	4.33	4.25	4.33	4.32	3.11
period1	male	*GBeta*	3.76	1.30	3.78	3.71	2.02	3.38	2.88	3.39	3.33	0.84
period1	male	*Gdiff*	0.87	0.29	0.88	0.86	0.69	0.78	0.68	0.78	0.77	0.27
period1	male	*Gshape*	6.14	2.67	6.18	6.05	10.33	5	5	5	5	5
period1	male	*GCV*	0.5	0.5	0.5	0.5	0.5	0.35	0.35	0.35	0.35	0.47
period1	female	*Galpha*	1.61	1.54	1.64	1.61	1.94	2.15	2.16	2.15	2.16	2.08
period1	female	*Gbeta*	1.29	1.21	1.28	1.30	0.64	0.23	0.05	0.04	0.04	0.01
period1	female	*Gdiff*	0.80	0.79	0.79	0.81	0.33	0.11	0.02	0.02	0.02	0.00
period1	female	*Gshape*	12.55	12.86	12.22	12.73	7.41	5	5	5	5	5
period1	female	*GCV*	1	1	1	1	1	0.83	0.86	0.84	0.84	1.03
period2	male	*Galpha*	2.18	2.16	2.18	2.18		2.34	2.32	2.34	2.34	
period2	male	*GBeta*	1.38	1.73	1.35	1.44		0.66	0.57	0.68	0.66	
period2	male	*Gdiff*	0.63	0.80	0.61	0.66		0.28	0.25	0.29	0.28	
period2	male	*Gshape*	13.02	15.00	12.82	13.18		5	5	5	5	
period2	male	*GCV*	0.5	0.5	0.5	0.5		0.45	0.47	0.46	0.45	
period2	female	*Galpha*	2.36	1.95	2.39	2.34		1.73	1.23	1.70	1.68	
period2	female	*Gbeta*	0.01	0.01	0.01	0.03		0.01	0.01	0.12	0.10	
period2	female	*Gdiff*	0.01	0.00	0.00	0.01		0.01	0.01	0.07	0.06	
period2	female	*Gshape*	5.31	6.48	5.05	5.40		5	5	5	5	
period2	female	*GCV*	1	1	1	1		1.448925	2.04447	1.45296	1.48134	
		vuln1	0.963	0.976	0.956	0.957	0.863	0.894	0.947	0.890	0.893	0.939
		vuln2	0.058	0.011	0.088	0.054	0.036	0.107	0.068	0.128	0.128	0.153
		vuln3	0.318	0.103	0.441	0.286	0.300	0.704	0.241	0.816	0.763	0.741
		vuln4	0.098	0.031	0.131	0.088	0.080	0.189	0.068	0.219	0.207	0.207
epoch 1	male	*Sel_L*	7.5	7.2	7.8	7.5	8.4	7.3	7.5	8.6	8.3	9.7
epoch 1	male	*SelMax*	58.3	58.9	58.6	58.6	59.2	60.2	59.8	62.7	62.4	64.3
epoch 1	female	*Sel_L*	11.3	10.5	11.0	11.1	11.2	11.8	11.6	11.9	11.9	13.3
epoch 1	female	*SelMax*	66.4	59.4	67.6	65.6	66.6	72.6	67.0	74.2	74.0	76.7
epoch 2	male	*Sel_L*	7.4	8.3	7.2	7.6	6.5	5.4	5.4	5.4	5.4	5.4

			Fixed *GCV*					Fixed *Gshape*				
					M prior	poo	one			M prior	poo	one
Growth	Sex	Quantity	base	*M*= 0.12	uniform	lag 2	epoch	base	*M*= 0.12	uniform	lag 2	epoch
epoch 2	male	*SelMax*	55.7	57.0	55.2	56.0	54.6	55.1	54.3	55.3	55.2	54.4
epoch 2	female	*Sel_L*	12.1	11.0	12.0	12.0	13.0	13.7	11.3	13.4	13.4	13.3
epoch 2	female	*SelMax*	66.0	59.3	67.7	65.6	67.8	74.5	64.0	74.4	74.1	74.3

Table 11: Median indicators in the McMC sensitivity trials and probability indicators.

	Fixed *GCV*					Fixed *Gshape*				
			M prior	poo	one			*M* prior	poo	one
	base	*M* = 0.12	uniform	lag 2	epoch	base	*M* = 0.12	uniform	lag 2	epoch
Bmin	194.3	161.1	204.5	187.0	156.2	334.3	318.3	332.0	333.8	254.2
B2014	704.1	552.8	740.0	657.2	533.9	1001.2	1018.4	983.7	933.8	875.3
Bref	633.8	669.5	637.3	619.3	572.1	1134.7	1243.0	1164.2	1137.8	915.6
B2017	596.3	459.7	630.4	516.6	439.5	690.1	686.7	669.8	628.0	812.4
Bmsy	212.8	136.6	227.0	202.3	216.0	211.7	172.1	214.6	211.4	306.7
MSY	242.6	163.3	252.8	236.3	245.1	212.4	113.8	213.7	207.5	257.0
Fmult	6.02	4.59	6.06	5.82	4.24	7.34	3.9	7.17	6.68	4.62
SSB2013	1243.7	1760.8	1194.3	1246.8	1190.7	2389.7	2560.2	2335.0	2256.3	1728.0
SSB2017	1273.0	1865.1	1205.5	1235.3	1213.5	2241.2	2437.6	2192.1	2085.6	1762.8
SSBmsy	880.8	1115.9	847.0	885.2	996.5	1544.9	1317.4	1531.4	1494.2	1410.0
CPUE2013	2.094	2.054	2.093	2.098	1.974	1.714	1.762	1.711	1.686	1.948
CPUE2017	1.662	1.603	1.640	1.454	1.467	1.003	1.005	1.002	0.927	1.697
CPUEmsy	0.288	0.232	0.299	0.286	0.414	0.196	0.202	0.202	0.206	0.438
B2014/Bmin	3.640	3.426	3.637	3.511	3.428	3.009	3.221	2.955	2.833	3.426
B2014/Bref	1.119	0.801	1.160	1.063	0.937	0.886	0.813	0.843	0.822	0.968
B2014/Bmsy	3.333	3.923	3.271	3.235	2.466	4.725	5.974	4.552	4.457	2.865
B2017/B2014	0.846	0.865	0.847	0.783	0.825	0.686	0.663	0.683	0.666	0.913
B2017/Bref	0.943	0.680	0.986	0.837	0.765	0.608	0.549	0.576	0.549	0.890
B2017/Bmsy	2.797	3.395	2.763	2.560	2.031	3.234	3.952	3.156	2.977	2.647
SSB2013/SSB0	0.697	0.692	0.693	0.693	0.738	1.068	1.054	1.026	1.009	0.820
SSB2017/SSB0	0.713	0.732	0.700	0.689	0.750	0.995	1.003	0.960	0.928	0.836
SSB2013/SSBmsy	1.410	1.579	1.405	1.408	1.197	1.549	1.952	1.528	1.522	1.222
SSB2017/SSBmsy	1.433	1.664	1.429	1.398	1.214	1.449	1.849	1.439	1.407	1.245

	Fixed *GCV*					Fixed *Gshape*				
	base	*M* = 0.12	*M* prior uniform	poo lag 2	one epoch	base	*M* = 0.12	*M* prior uniform	poo lag 2	one epoch
SSB2017/SSB2013	1.019	1.062	1.014	0.990	1.017	0.930	0.947	0.929	0.918	1.017
USL2013	0.238	0.302	0.226	0.251	0.311	0.157	0.159	0.161	0.167	0.191
USL2017	0.292	0.378	0.276	0.336	0.394	0.252	0.253	0.259	0.277	0.214
USL2017/USL2013	1.210	1.200	1.208	1.333	1.257	1.599	1.617	1.610	1.680	1.129
Btot2013	2898.7	3002.5	2918.3	2853.6	2568.0	5821.1	4851.7	5869.7	5539.7	4187.7
Btot2013/Btot0	0.495	0.376	0.517	0.485	0.485	0.672	0.493	0.676	0.651	0.633
Ntot2013	8950000	8500000	9110000	8800000	7900000	19200000	14100000	19800000	18600000	13800000
Ntot2013/Ntot0	0.756	0.703	0.764	0.757	0.654	0.909	0.966	0.905	0.891	0.778
P(B2014>Bmin)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(B2014>Bref)	0.75	0.11	0.79	0.67	0.35	0.19	0.07	0.13	0.11	0.42
P(B2014>Bmsy)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(B2017>Bmin)	1.00	0.99	1.00	1.00	0.99	0.99	1.00	1.00	0.99	1.00
P(B2017>Bref)	0.44	0.12	0.48	0.25	0.23	0.02	0.00	0.01	0.01	0.32
P(B2017>Bmsy)	1.00	1.00	1.00	1.00	0.96	1.00	1.00	1.00	1.00	1.00
P(B2017>B2014	0.21	0.25	0.21	0.14	0.22	0.02	0.00	0.01	0.00	0.32
P(SSB2013>SSBmsy)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(SSB2017>SSBmsy)	1.00	1.00	1.00	1.00	0.96	1.00	1.00	0.99	0.99	0.97
P(USL2017>USL2013	0.77	0.74	0.79	0.88	0.80	1.00	1.00	0.99	1.00	0.71
P(SSB2013<0.2SSB0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(SSB2017<0.2SSB0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(SSB2013<0.1SSB0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(SSB2017<0.1SSB0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 12: CRA 3: Effect of the minimum change threshold on the industry-proposed rule.

	Fixed *GCV*						Fixed *Gshape*					
Threshhold	0.0%	5.0%	7.5%	10.0%	12.5%	15.0%	0.0%	5.0%	7.5%	10.0%	12.5%	15.0%
average comm. catch	167.6	168.3	167.7	166.9	166.4	165.7	165.8	165.4	165.5	165.5	165.4	167.6
average comm. catch	220.5	220.3	220.2	220.3	220.9	220.3	215.3	215.4	215.6	215.2	215.8	215.7
average rec. catch	16.5	16.5	16.5	16.4	16.4	16.4	17.1	17.1	17.1	17.1	17.0	17.0
minimum CPUE	0.921	0.922	0.919	0.906	0.898	0.889	0.913	0.910	0.909	0.907	0.901	0.896
average CPUE	1.644	1.645	1.646	1.643	1.637	1.641	1.545	1.545	1.547	1.548	1.543	1.537
AAV	7.7	7.1	6.5	5.8	5.4	5.1	7.8	7.2	6.6	6.0	5.4	5.0
propn. changes	86.8%	57.2%	46.3%	37.7%	31.2%	26.8%	91.0%	59.8%	47.9%	38.8%	32.1%	27.3%
P(<plateau)	74.2%	74.2%	74.2%	74.2%	74.1%	74.2%	81.1%	81.0%	81.0%	81.0%	81.0%	81.1%
P(>plateau)	3.1%	3.2%	3.2%	3.2%	3.2%	3.3%	1.7%	1.7%	1.7%	1.7%	1.7%	1.8%
P(AWCPUE>1.0)	65.1%	65.1%	64.9%	64.6%	64.2%	63.9%	56.3%	56.3%	56.2%	56.0%	55.9%	55.7%
P(AWCPUE>1.5)	35.8%	35.9%	36.0%	35.8%	35.9%	35.9%	22.3%	22.4%	22.4%	22.4%	22.4%	22.4%

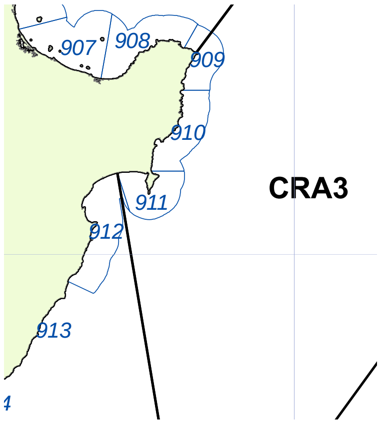

Figure 1: The CRA 3 stock area on the east coast of the North Island and its Statistical Areas 909, 910 and 911 (light blue).

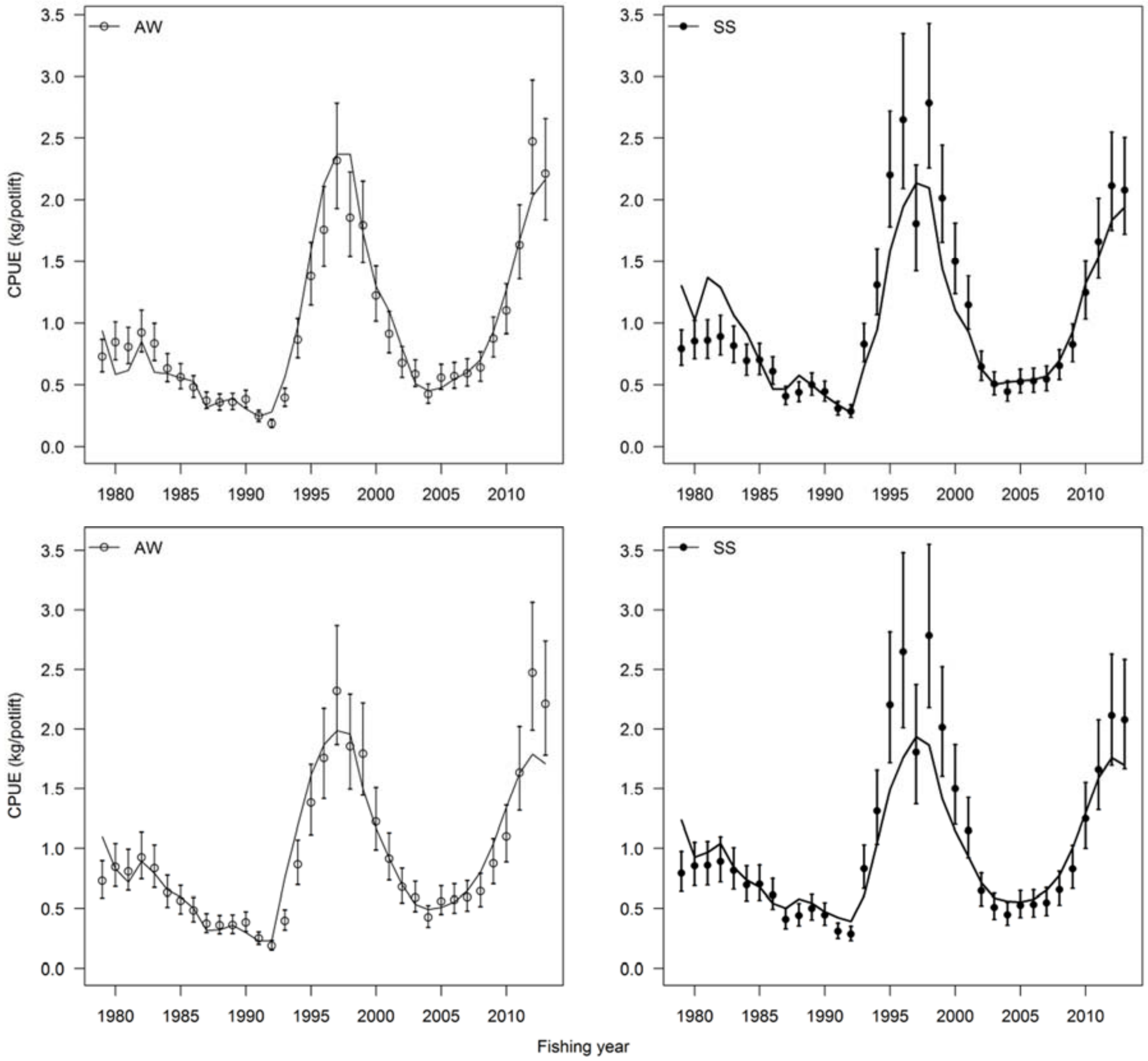

Figure 2: Fits to CPUE from the fixed *GCV* (upper) and the fixed *Gshape* base case MPDs; the solid line is the MPD predicted CPUE and the points with vertical bars are the observed CPUE with their standard errors.

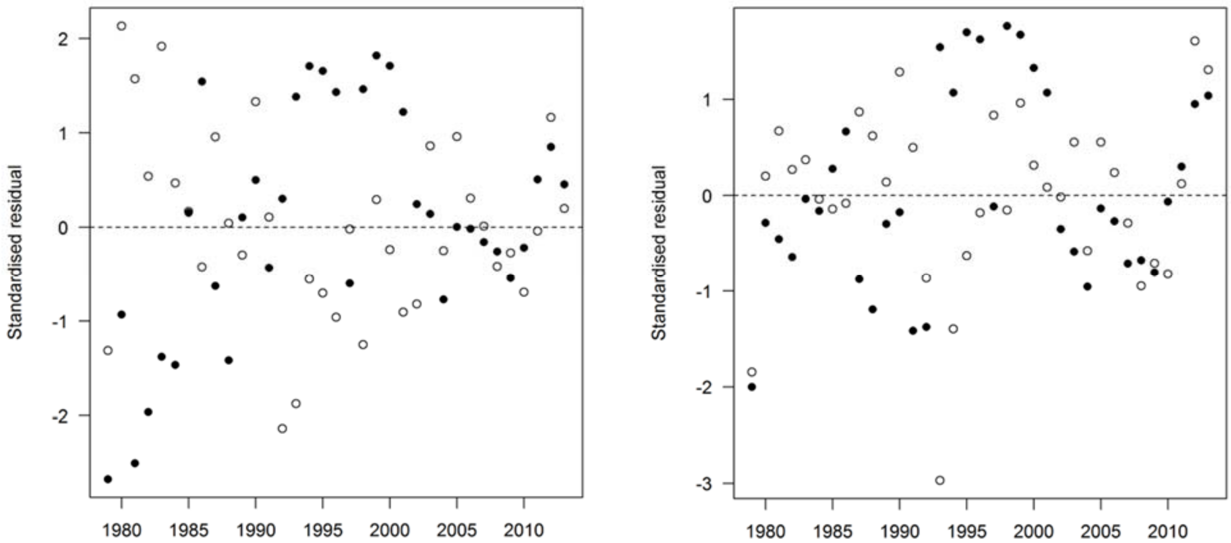

Figure 3: Residuals from the fits to CPUE from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs: open circles are AW and closed circles are SS; the dotted line shows zero.

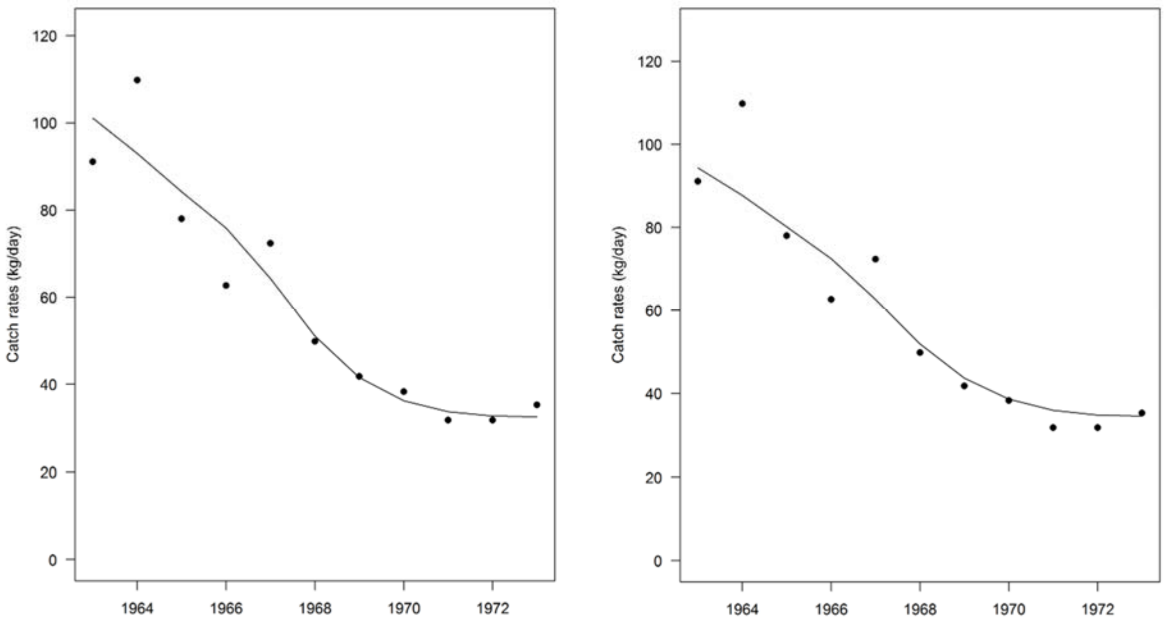

Figure 4: Fits to historical catch rate CR from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; the solid line is the MPD predicted CR and the points are the observed CR.

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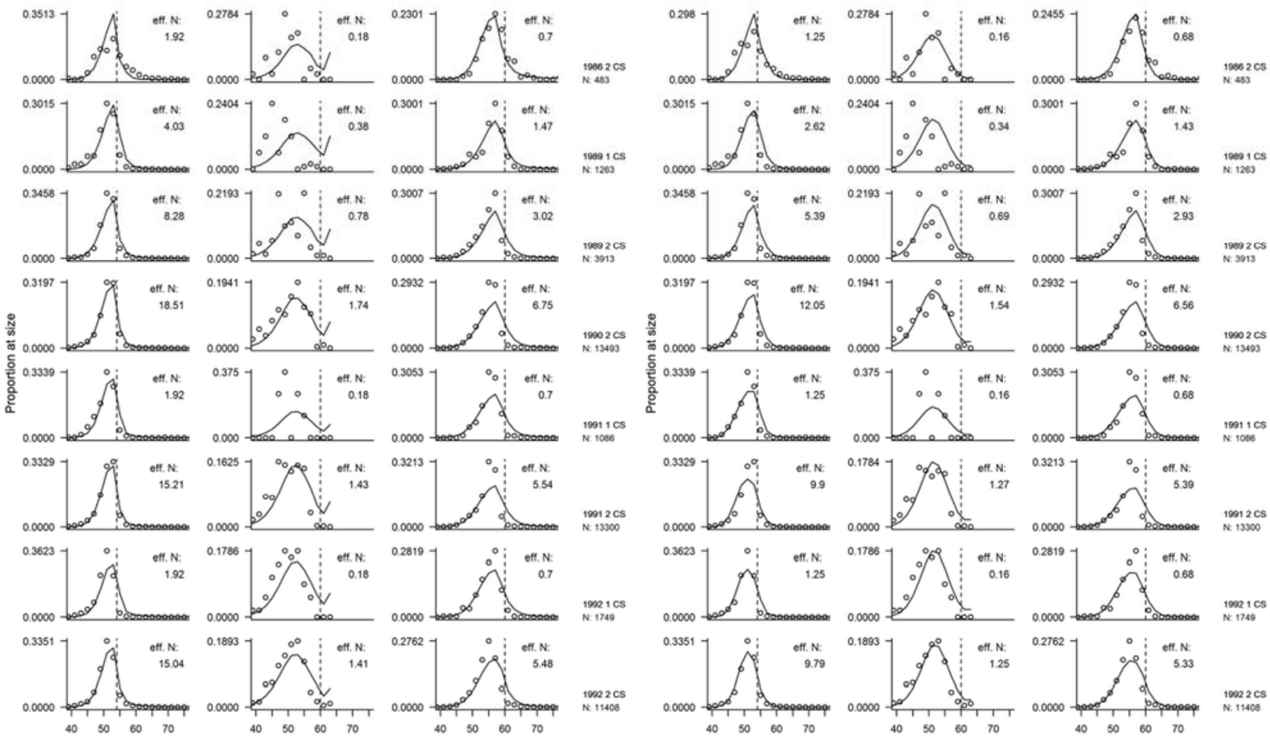


Figure 5: Fits to early LFs from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; each plot shows males on the left, immature females in the centre and mature females on the right; the open circles are observed proportions and the line is the predicted proportion; numbers in the plot show the effective sample sizes for each record while information at the right of each record is year, season (1 is AW, 2 SS), source (CS is observer catch sampling and LB is logbook data) and the number of fish measured.

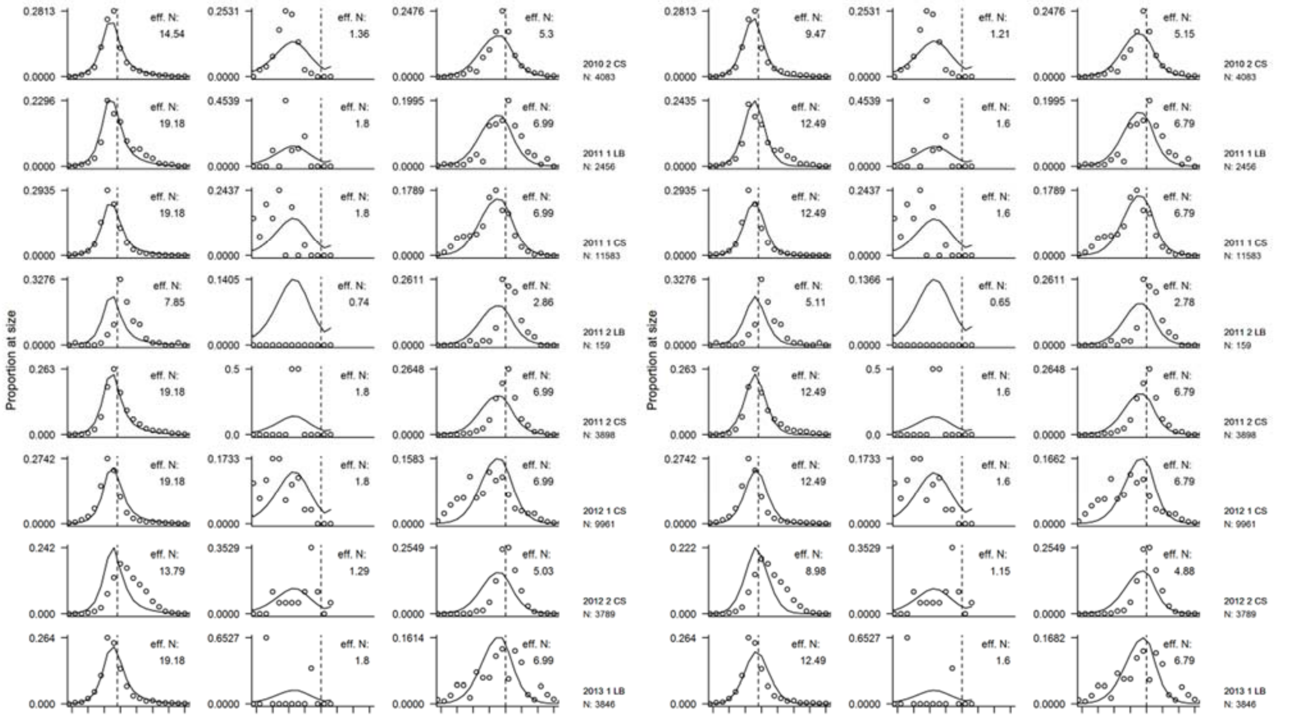


Figure 6: CRA 3: Fits to later LFs from the fixed GCV (left) and the fixed Gshape base case MPDs; see caption for Figure 5.

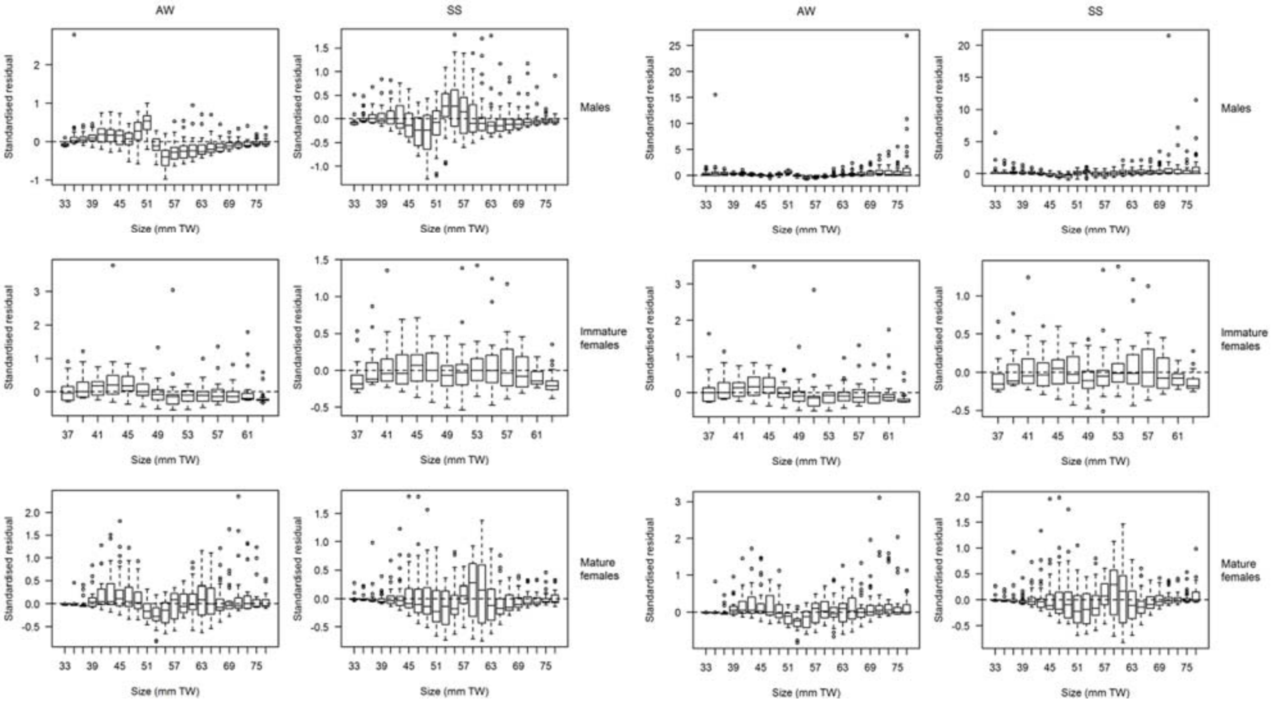


Figure 7: CRA 3: Box plots of residuals vs. size for the fits to LFs from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; each plot shows the sex groups from males on top to mature females on the bottom, AW on the left and SS on the right; the boxes contain 90% of the residuals and the dotted lines indicate 99%, with outliers shown.

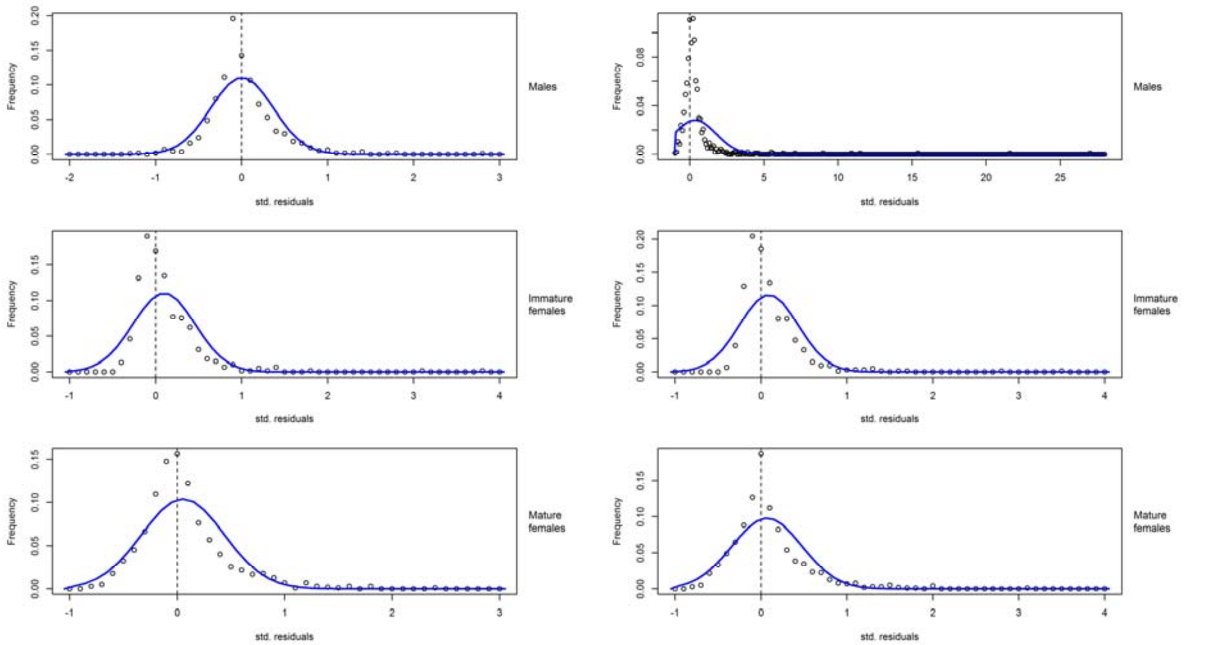


Figure 8: Distributions of residuals from the fits to LFs (open circles) by sex for the fixed *GCV* base case (left) and fixed *Gshape*; both are compared with the theoretical normal distributions (solid line).

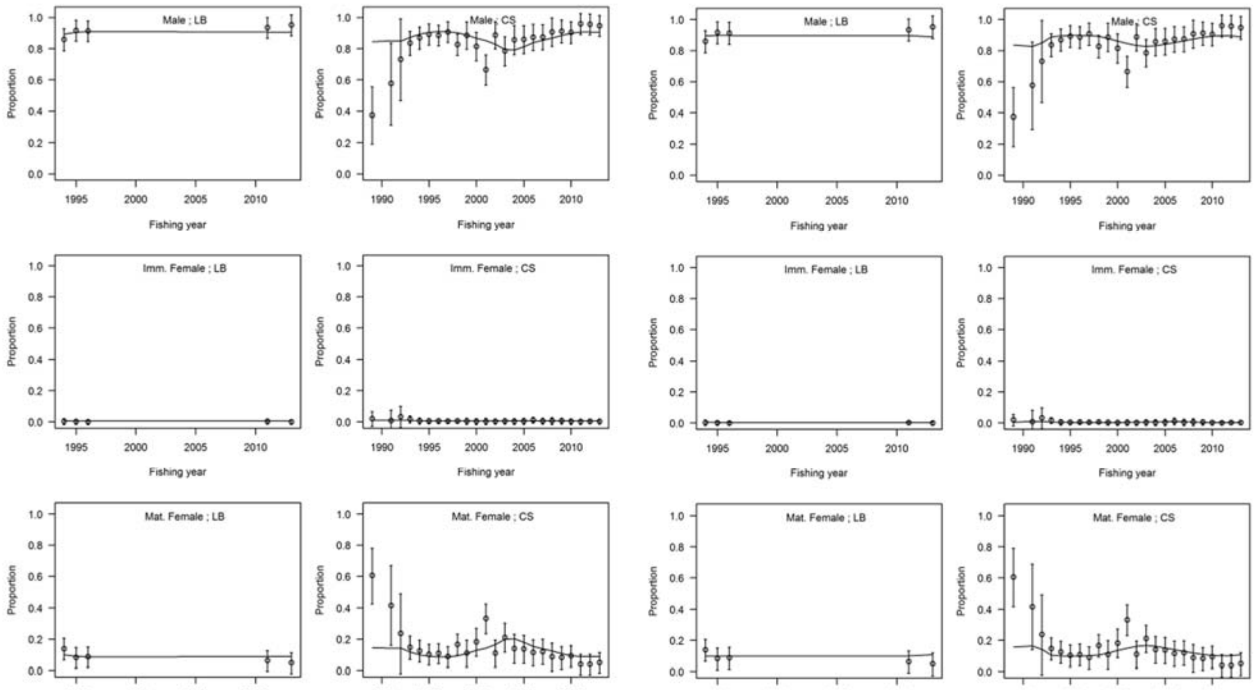


Figure 9: Fits to AW proportion-at-sex by year from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; open circles show the observed and the line shows the predicted proportions; bars show one standard deviation; LB refers to logbook data and CS to observer catch sampling.

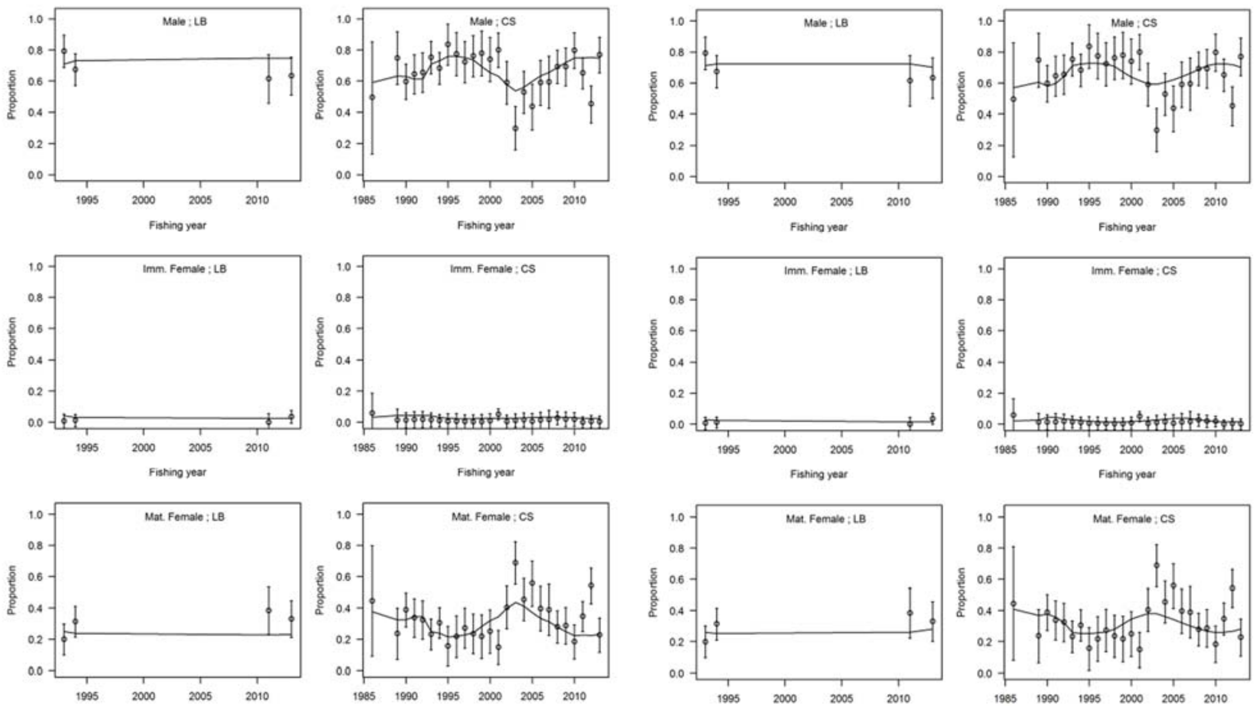


Figure 10: Fits to SS proportion-at-sex by year from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; open circles show the observed and the line shows the predicted proportions; bars show one standard deviation; LB refers to logbook data and CS to observer catch sampling.

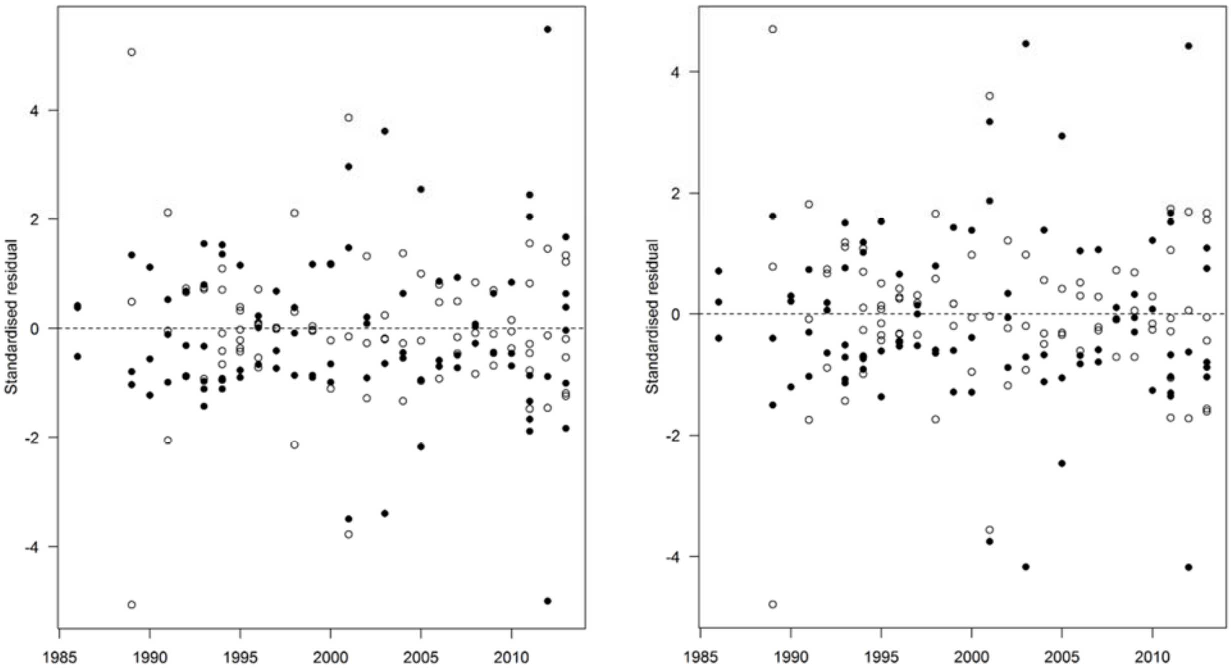


Figure 11: Residuals from the fit to proportions-at-sex from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; open circles show AW and closed circles show SS; the dotted line shows zero.

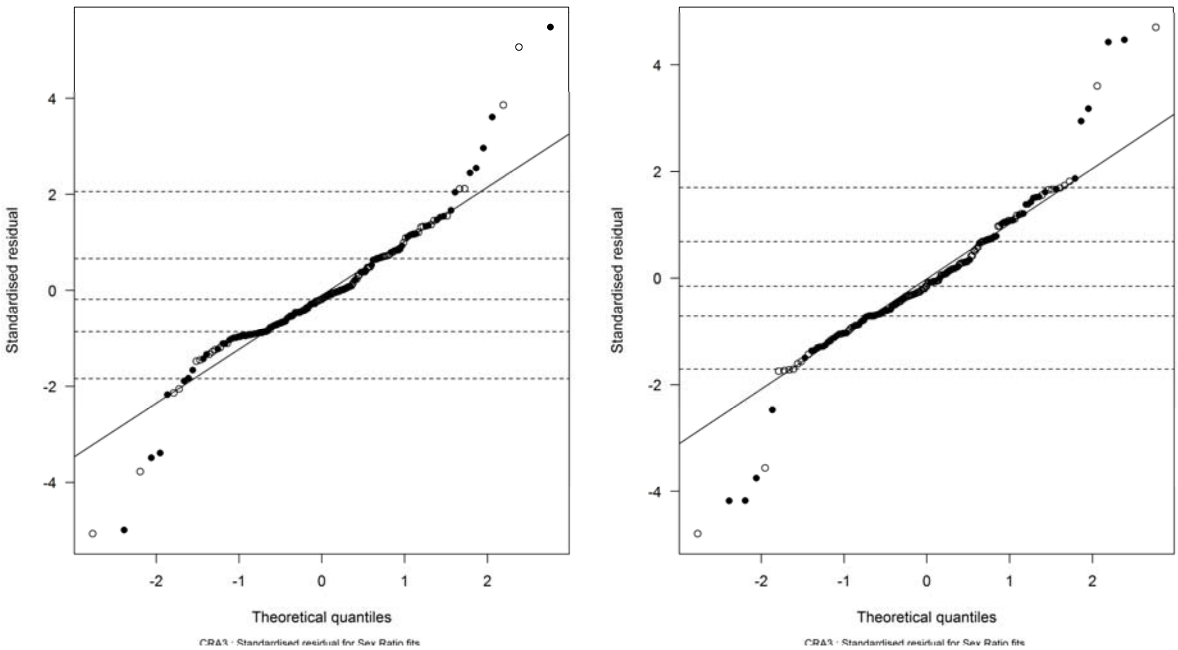


Figure 12: Q-Q plots from the fits to AW proportion-at-sex by year from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; open circles show AW and closed circles show SS while the solid line shows the theoretical distribution.

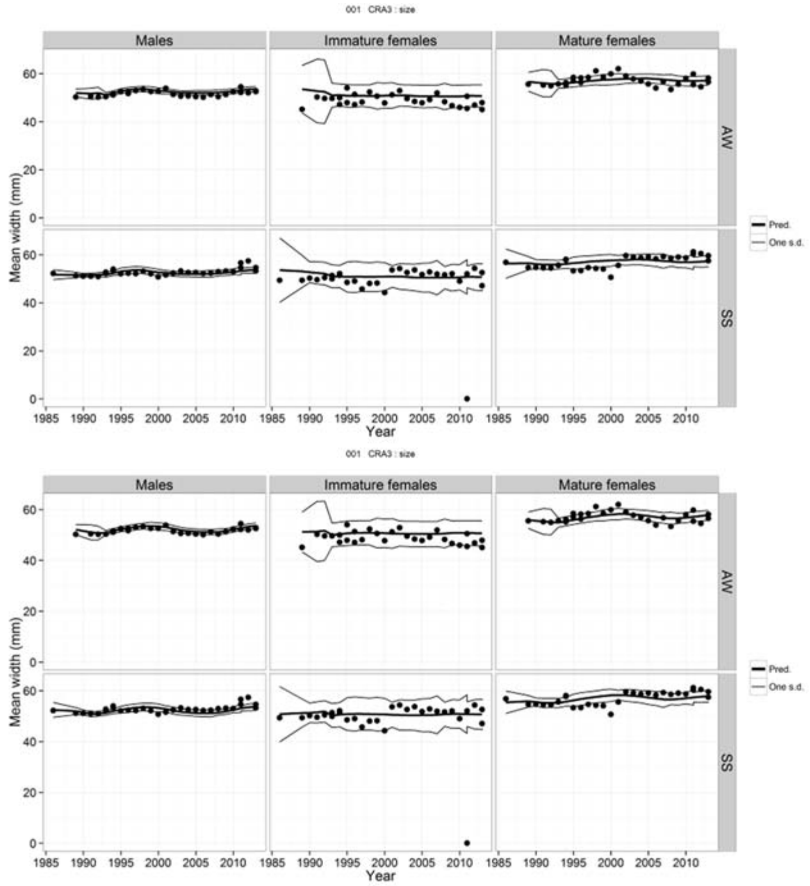


Figure 13: MPD fits to mean length from the fixed *GCV* (upper) and the fixed *Gshape* base case MPDs (heavy solid line) compared with the observed mean lengths (circles) and their standard deviations (lighter solid lines).

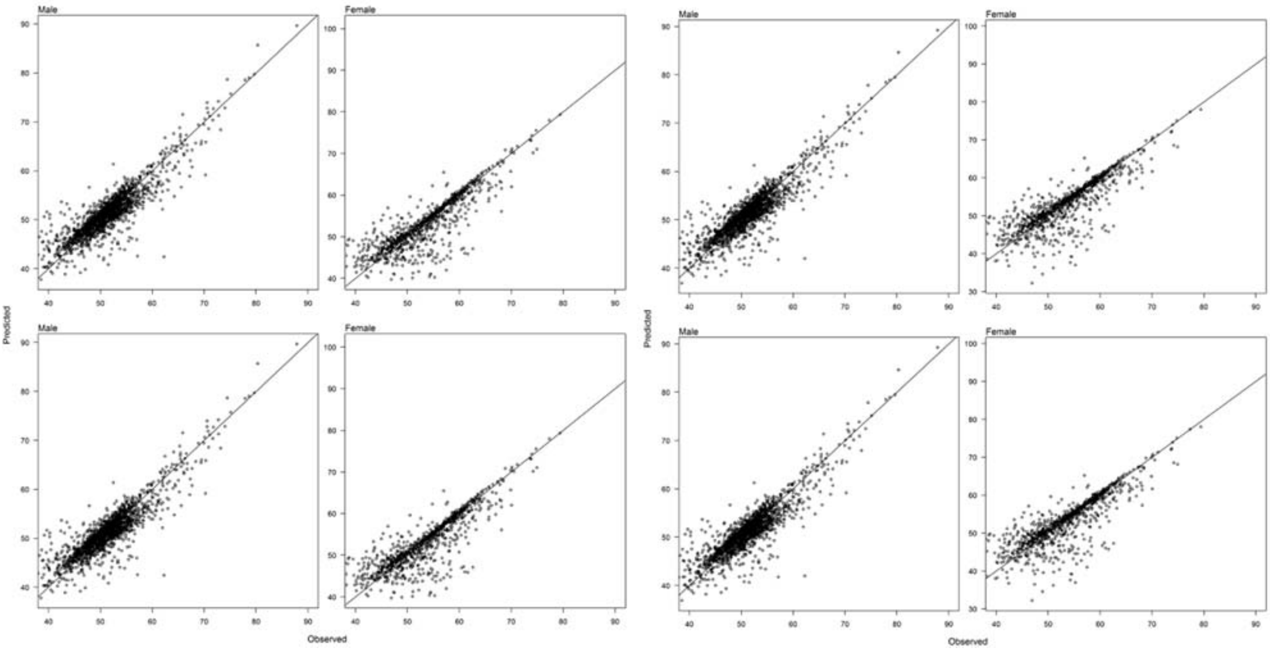


Figure 14: Predicted vs. observed sizes at recapture in the tag data (points) from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; males are on the left within each figure; the top figures are from the fit to the first tag data set and the bottom from the second; the line shows 1:1.

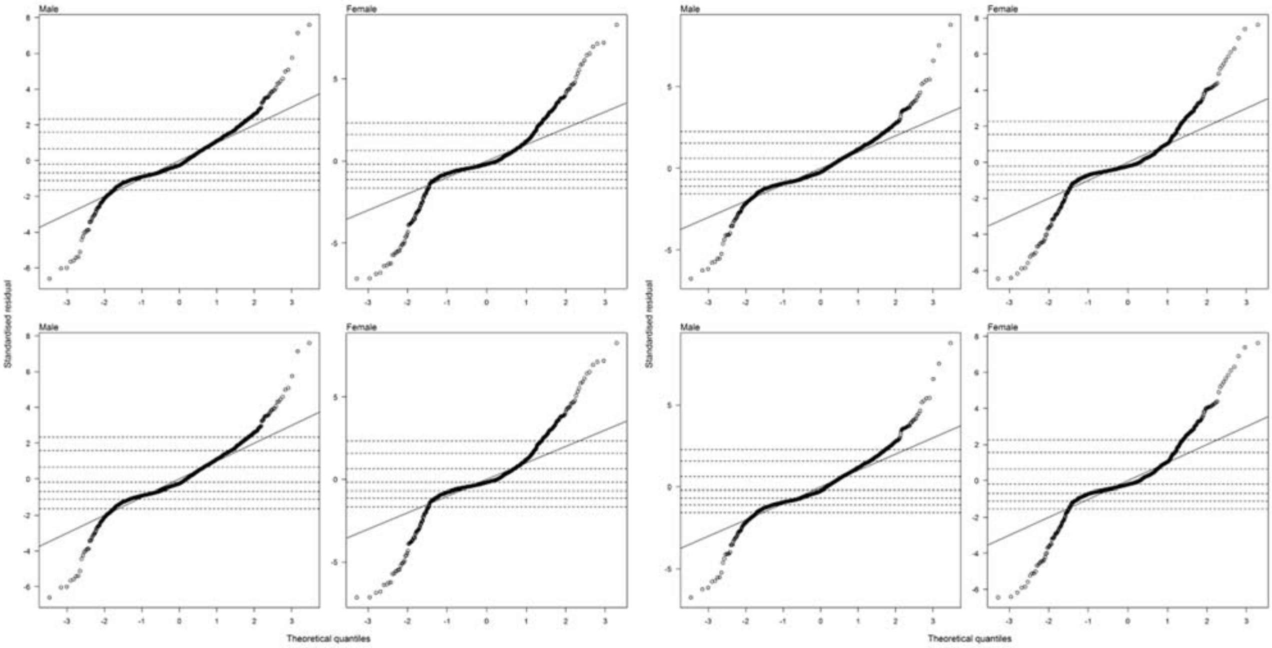


Figure 15: Q-Q plots of residuals from fits to the tag data from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; males are on the left within each figure; the top figures are from the fit to the first tag data set and the bottom from the second; while the solid line shows the theoretical distribution.

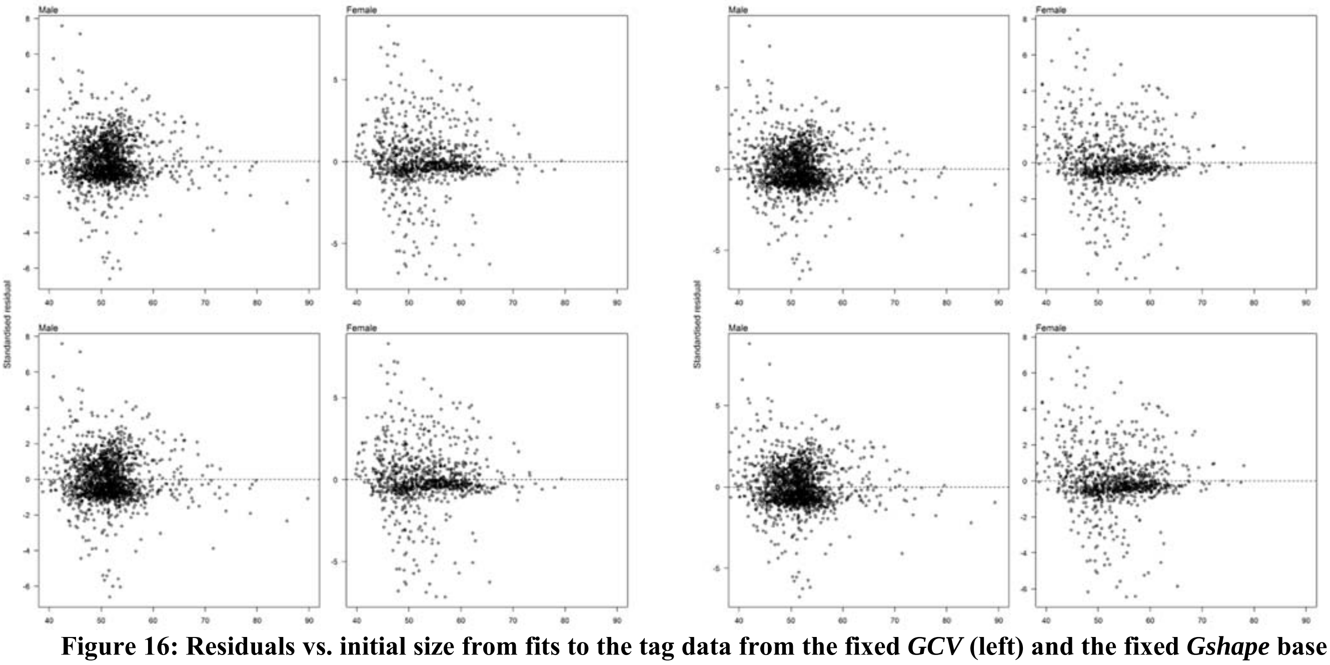


Figure 16: Residuals vs. initial size from fits to the tag data from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; males are on the left within each figure; the top figures are from the first growth parameter set and the bottom from the second; the dotted lines show zero.

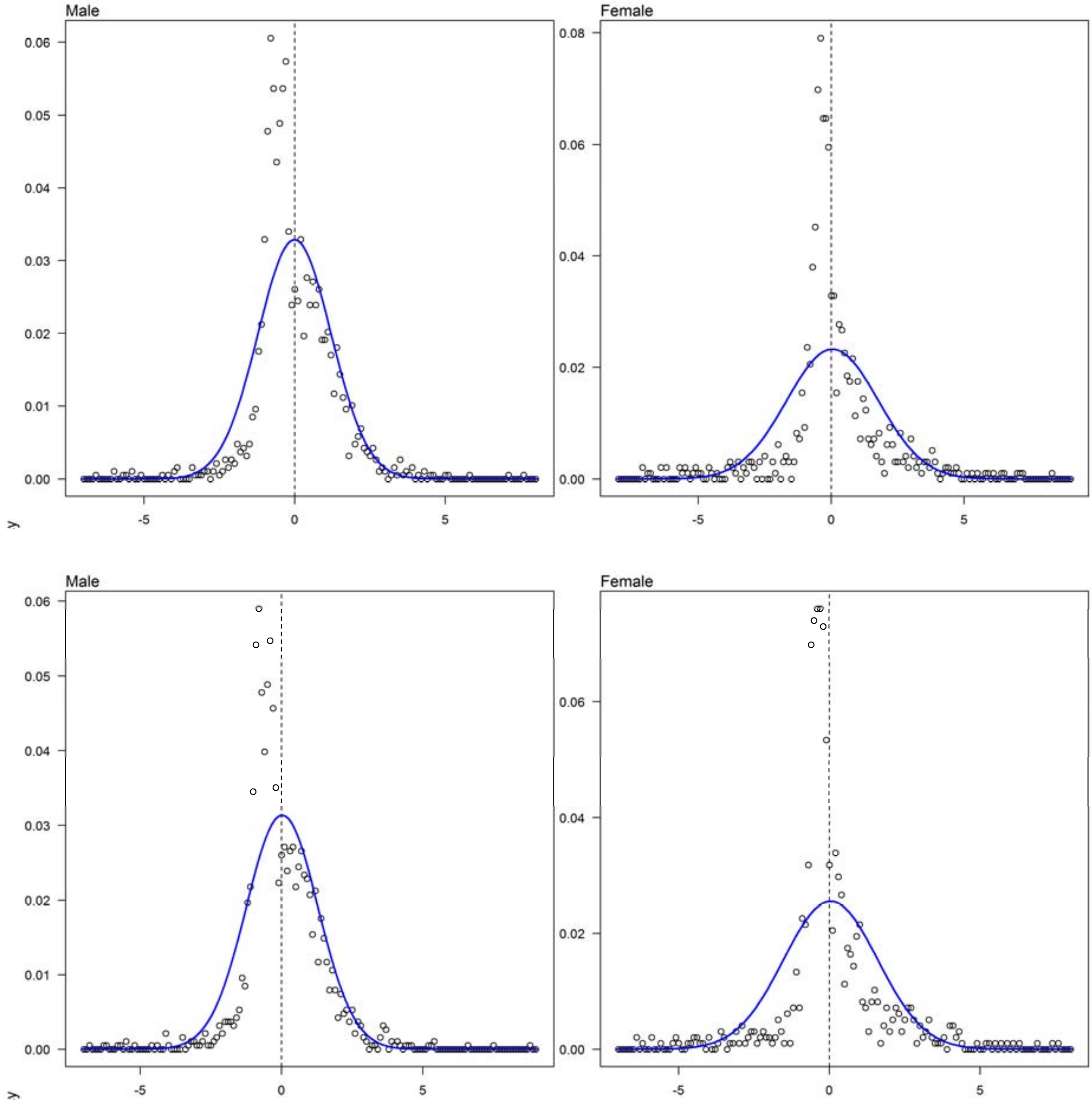
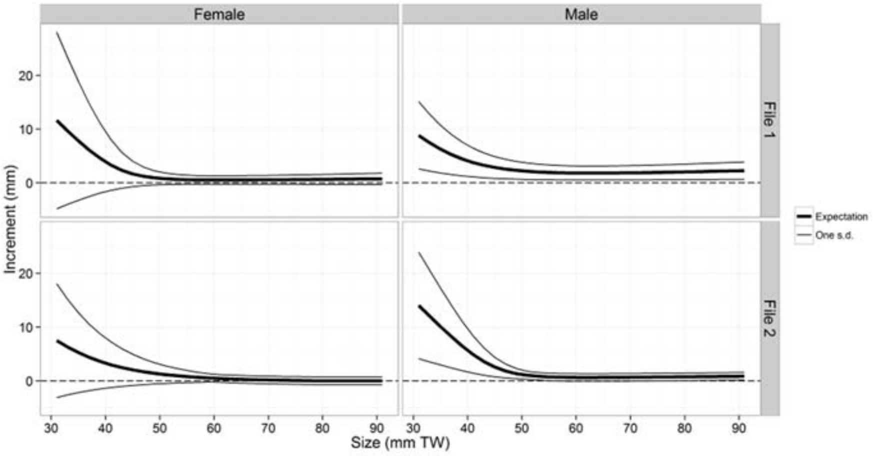


Figure 17: The distribution of normalised residuals from the fits to tag-recapture data (open circles) compared with a normal distribution (solid line) for the fixed *GCV* base case (upper) and fixed *Gshape*; males on the left.



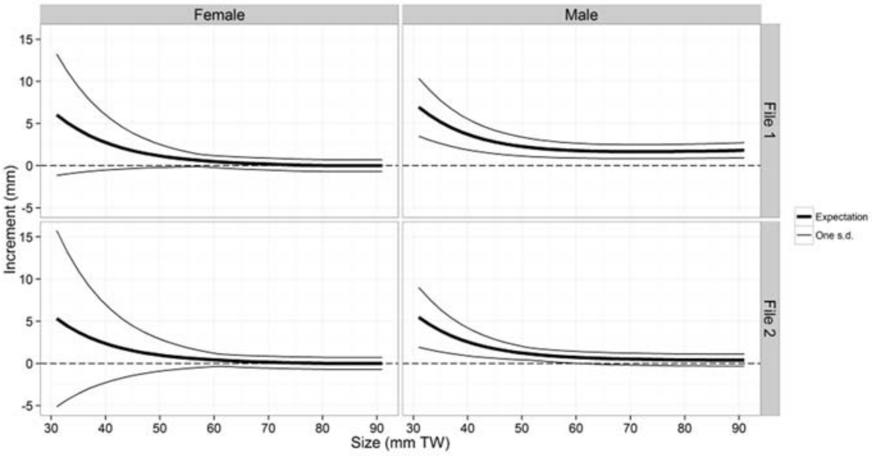


Figure 18: Predicted increments-at-length from the fixed *GCV* (top) and the fixed *Gshape* base case MPDs; males are on the left within each figure; in each figure the top figures are from the first growth parameter set and the bottom from the second; the central solid line shows the predicted increment and the lighted lines show the standard deviation of the predicted distribution of increments.

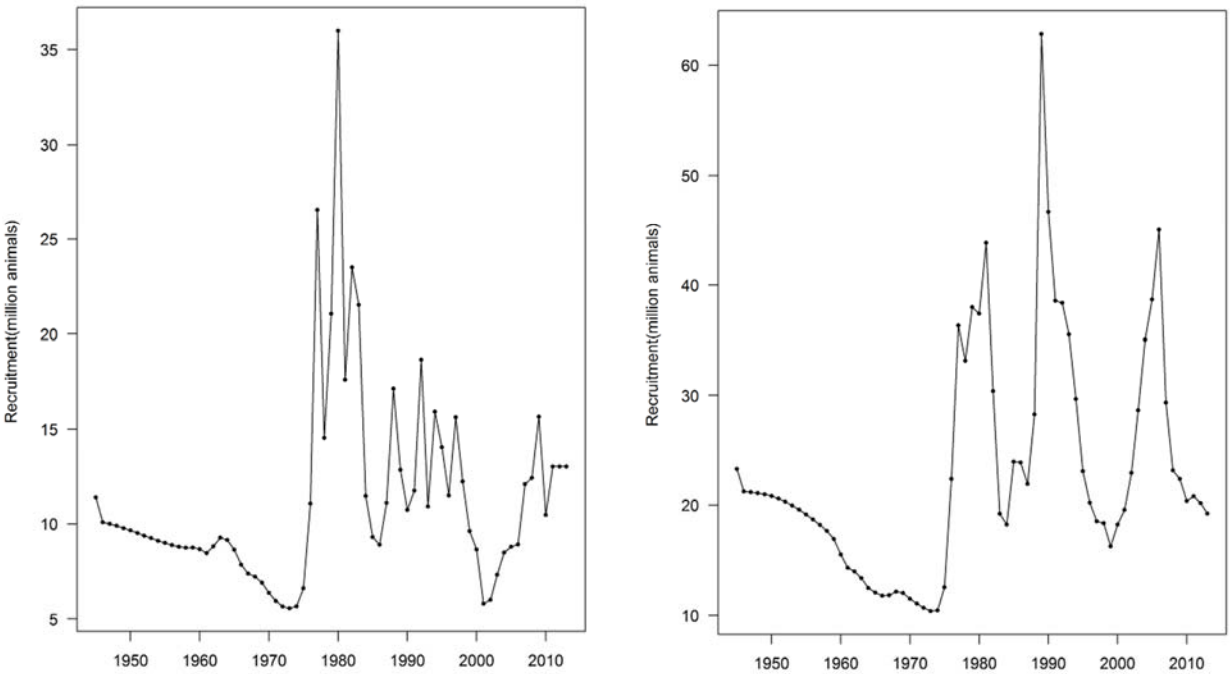


Figure 19: Recruitment trajectory from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs: both points and the solid lines show the MPD estimates.

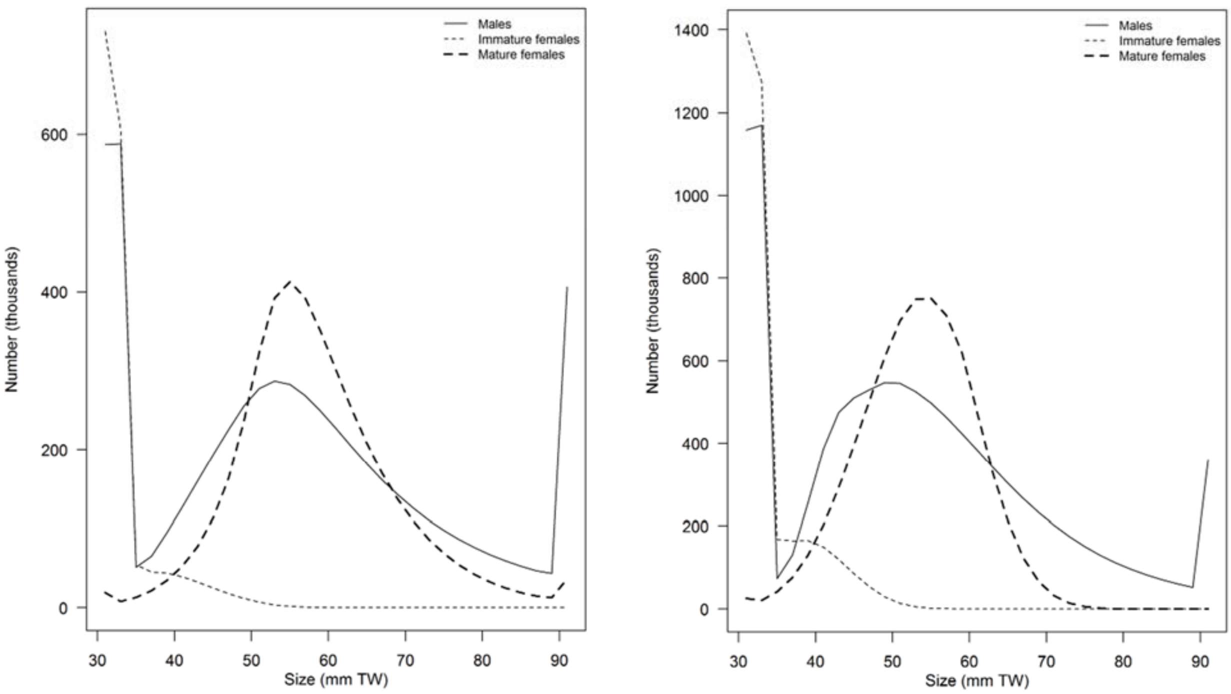


Figure 20: Initial length structure from the fixed *GCV* (left) and the fixed *Gshape* base case MPDs; the solid line shows males, the dotted line immature females and the dashed line mature females.

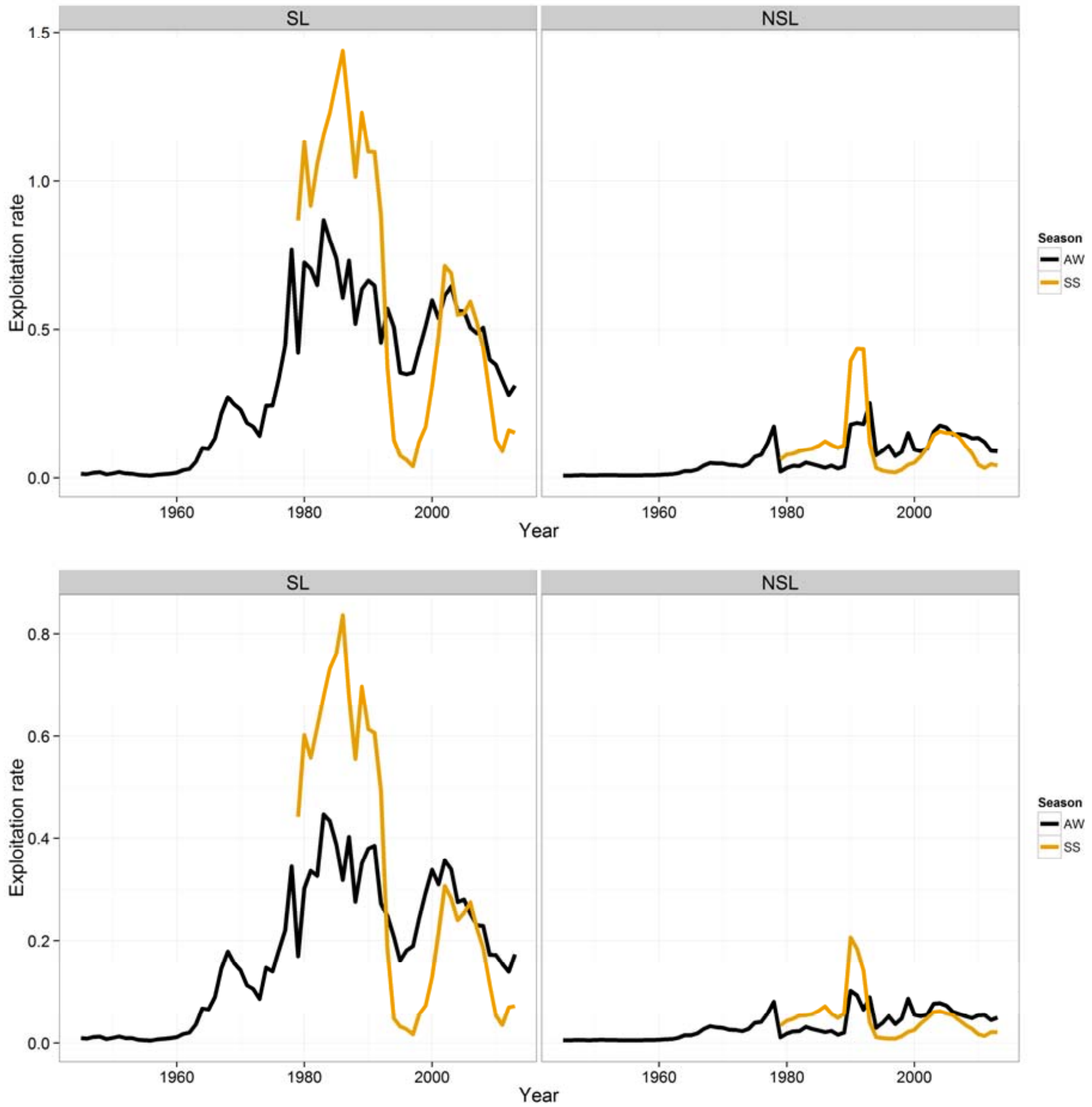


Figure 21: Exploitation rate trajectories from the fixed *GCV* (upper) and the fixed *Gshape* base case MPDs, with SL on the left and NSL on the right.

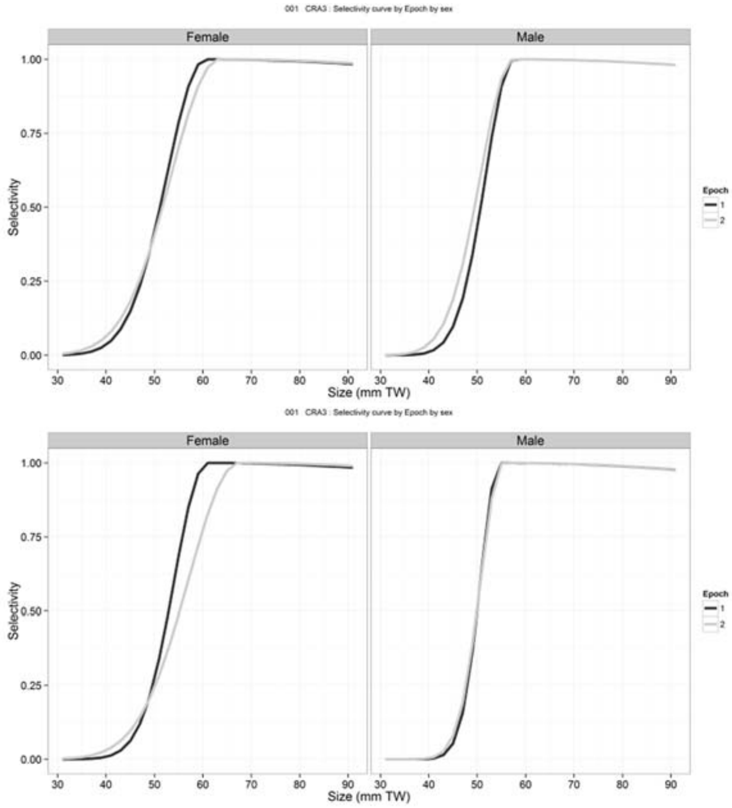


Figure 22: Estimated selectivity curves from the fixed *GCV* (upper) and the fixed *Gshape* base case MPDs, with black and grey lines showing the first and second epochs respectively.

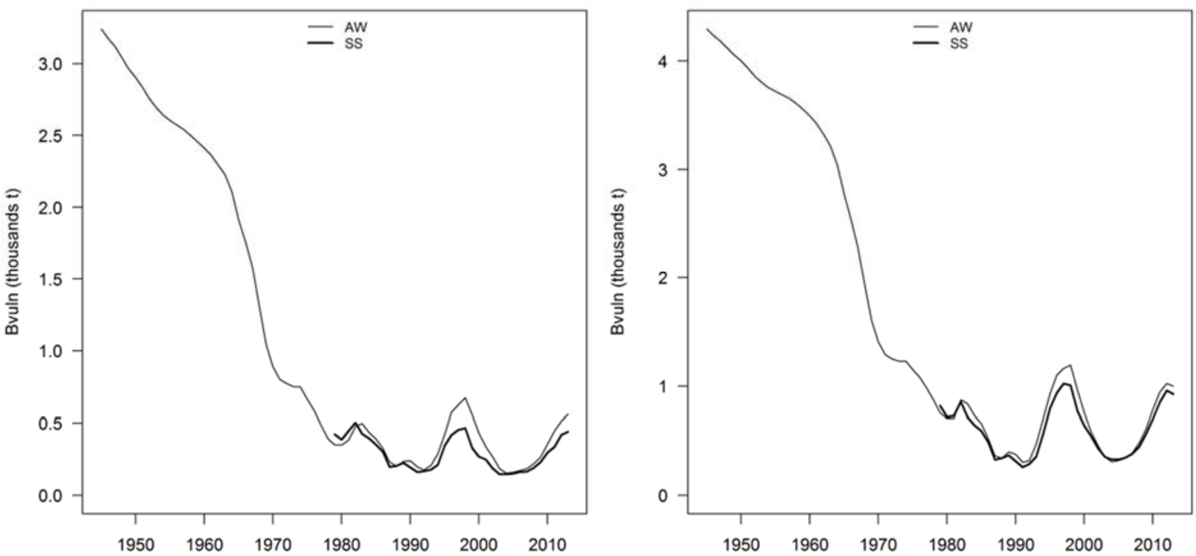


Figure 23: Vulnerable biomass trajectories from the fixed *GCV* (left) and fixed *Gshape* base case MPDs; the grey lines show AW and the black lines show SS.

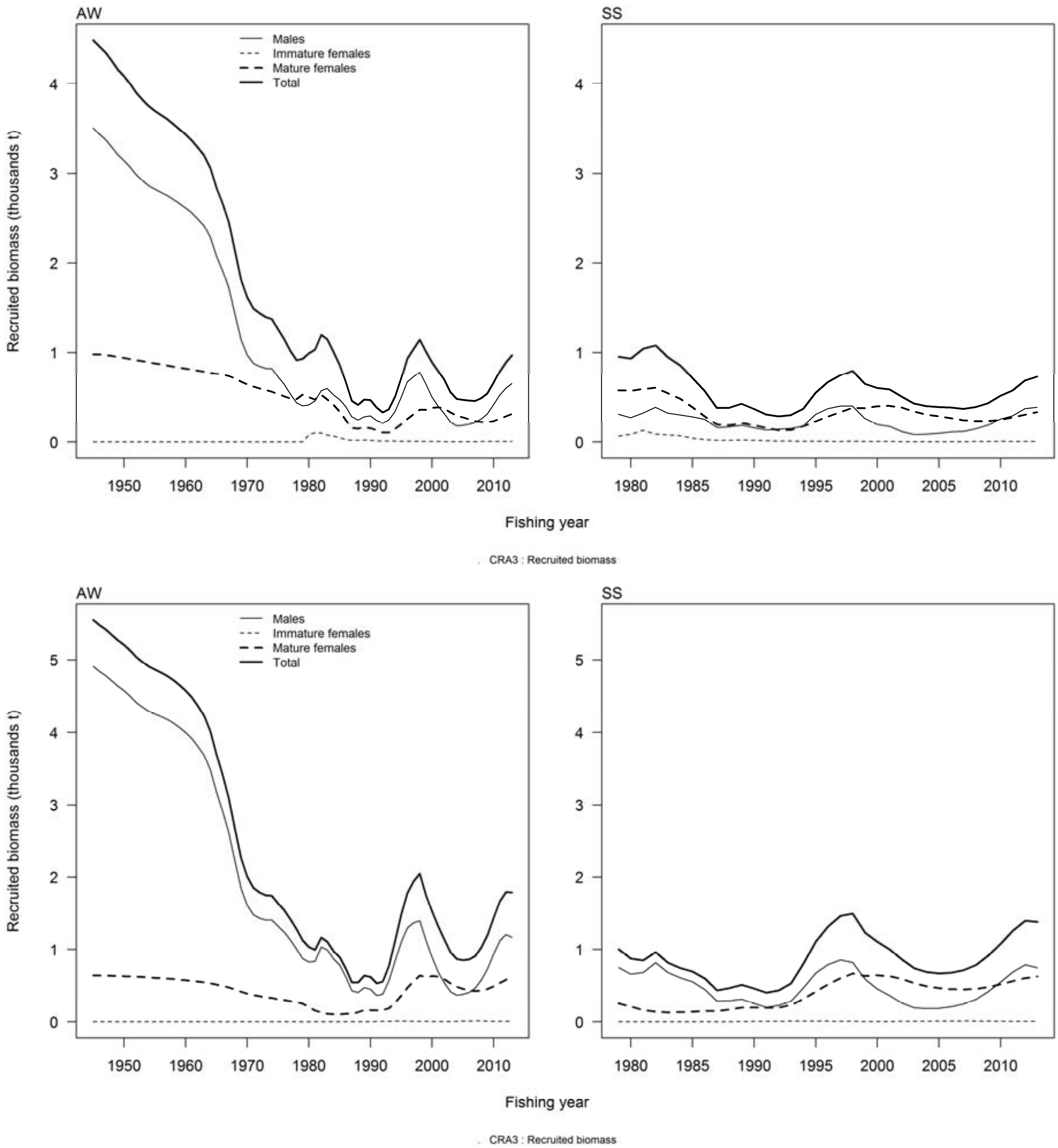


Figure 24: Recruited biomass trajectories by sex category from the fixed *GCV* base case (upper) and fixed *Gshape*; the heavy black uppermost solid line shows the total, the black line shows males, the dotted line immature females and the dashed line mature females.

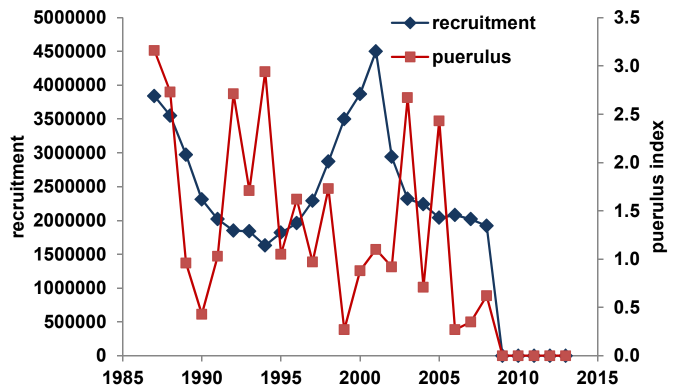


Figure 25: The relation between the puerulus indices and recruitment estimated by the fixed *Gshape* base case, compared with a lag of 5 years between settlement and recruitment to the model; the blue line and diamonds show the MPD recruitment estimates and the red line and squares show the observed standardised puerulus index.

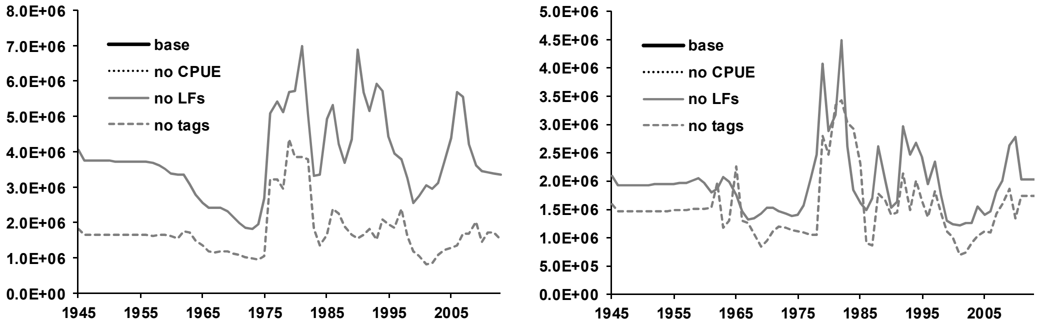


Figure 26: Recruitment trajectories in the base case (heavy black line) and those sensitivity trials that removed major data sets: fixed *Gshape* base case on the left and fixed *GCV* on the right; the light solid line shows no LFs, the dotted line shows no CPUE and the dashed line shows no tags.

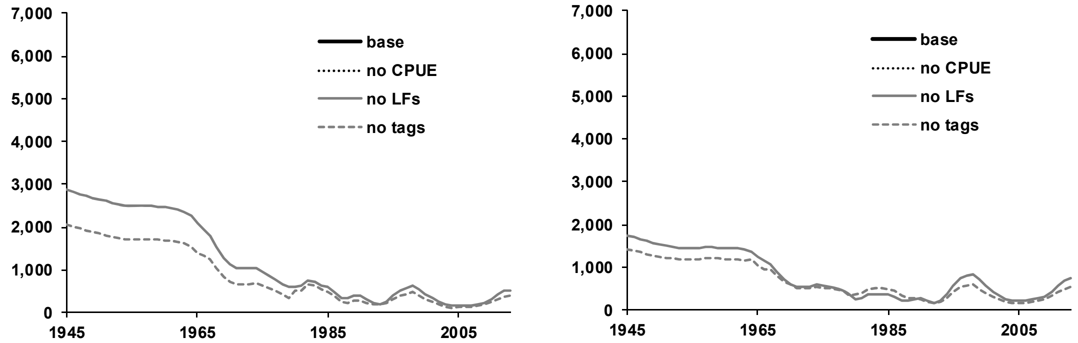


Figure 27: Vulnerable biomass trajectories in the base case (heavy black line) and those sensitivity trials that removed major data sets: fixed *Gshape* base case on the left and fixed *GCV* on the right; the light solid line shows no LFs, the dotted line shows no CPUE and the dashed line shows no tags.

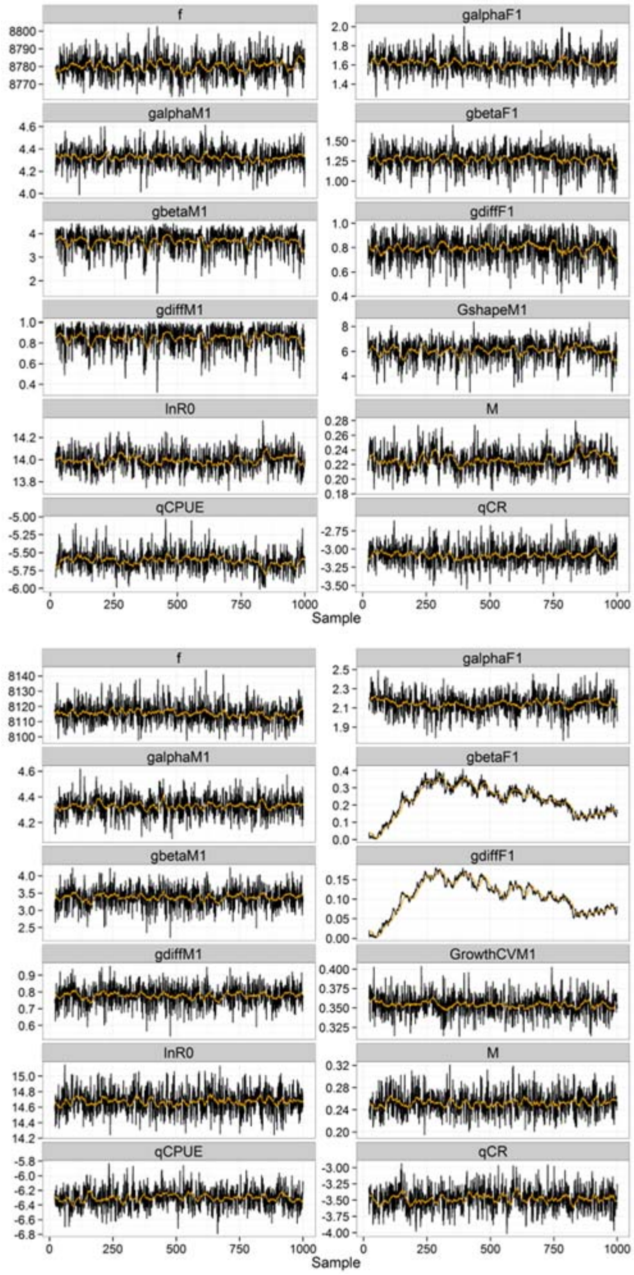


Figure 28: Sample traces from the fixed *GCV* (left) and fixed *Gshape* base case McMCs.

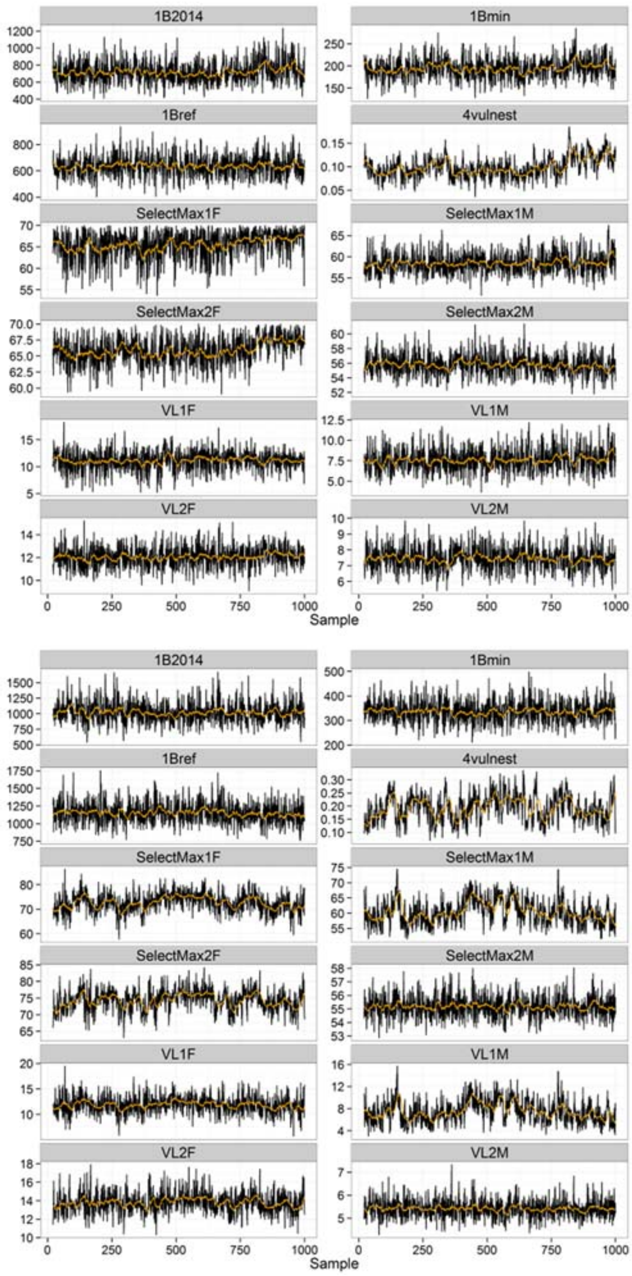


Figure 28 concluded.

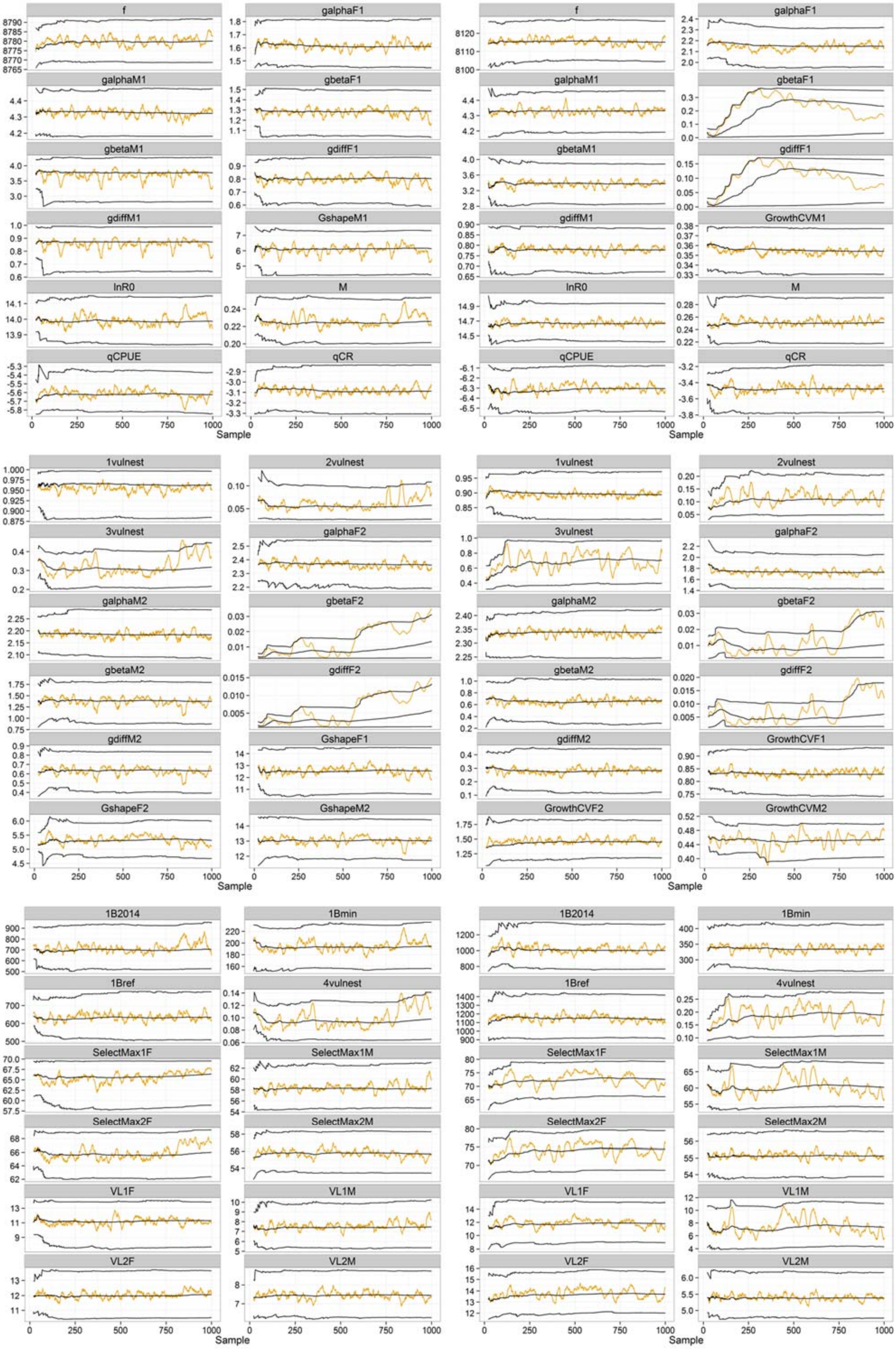


Figure 29: CRA 3: Diagnostic plots from the McMCs for the fixed *GCV* (left) and fixed *Gshape* base case McMCs.

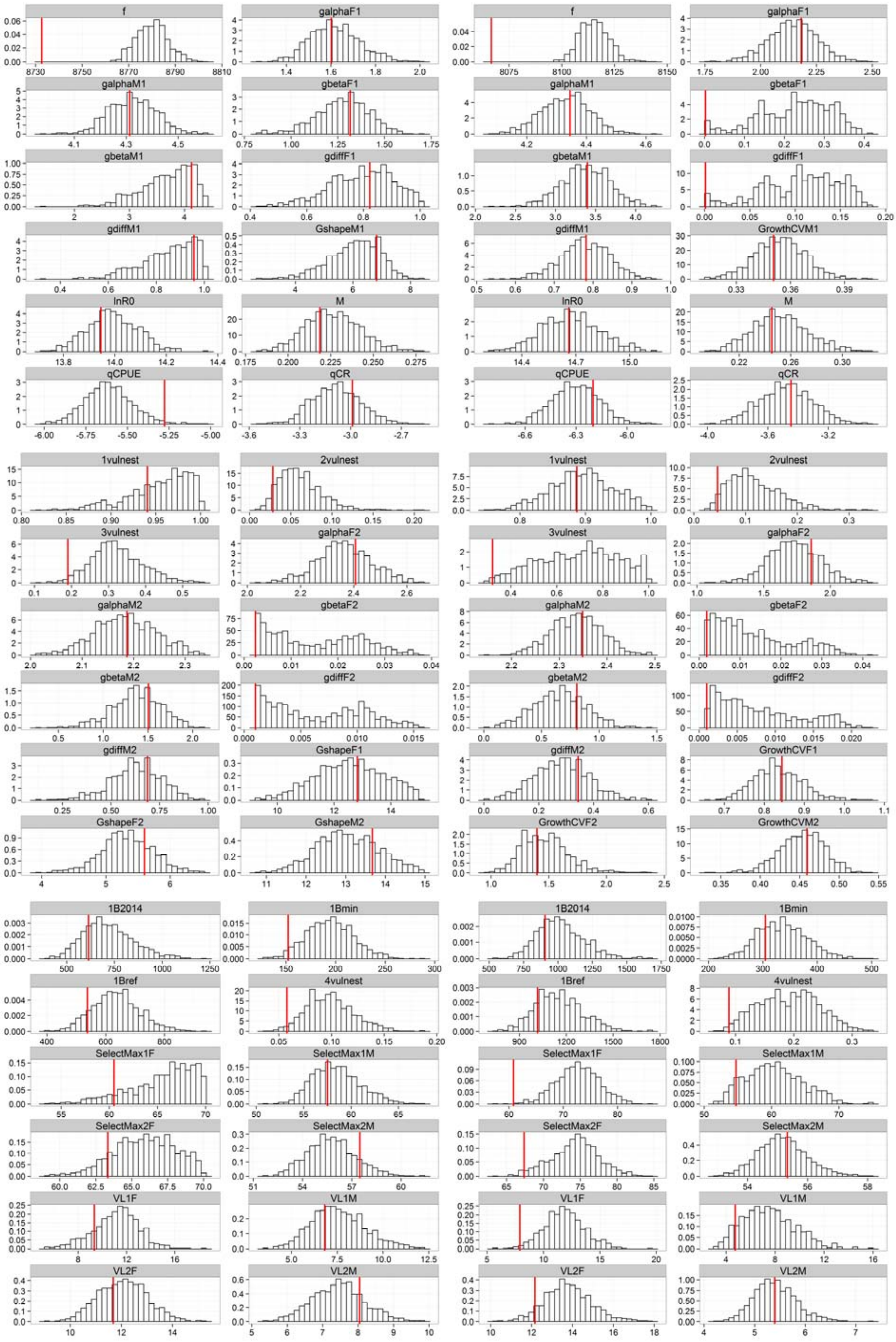


Figure 30: Posteriors from the fixed *GCV* base case (left) and fixed *Gshape*; the vertical lines show the MPD estimates.

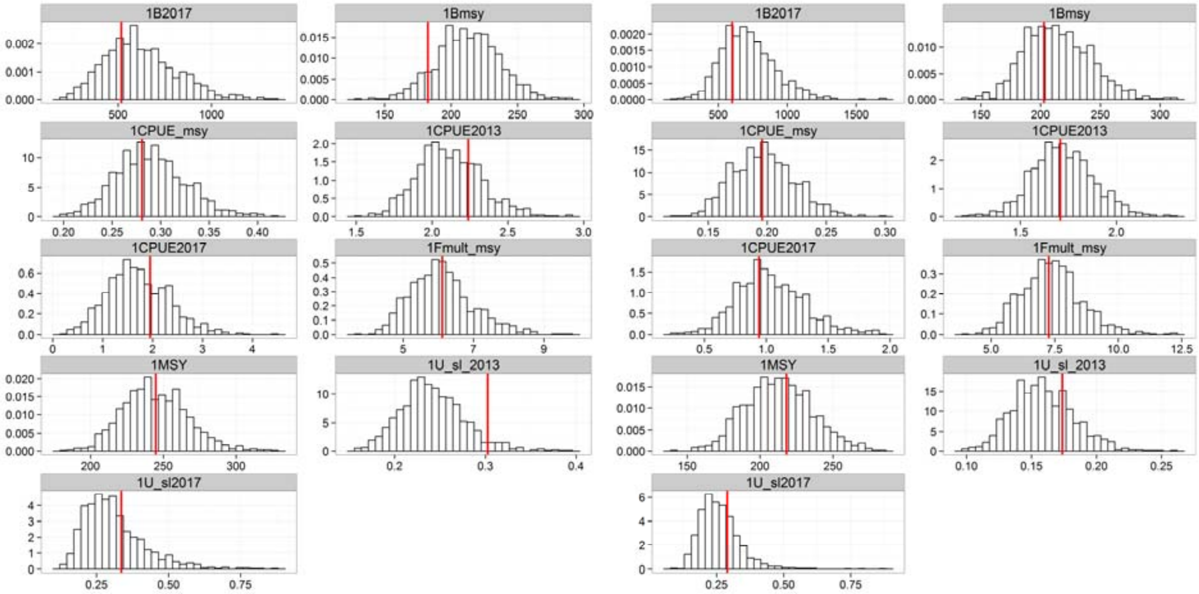


Figure 30 concluded.

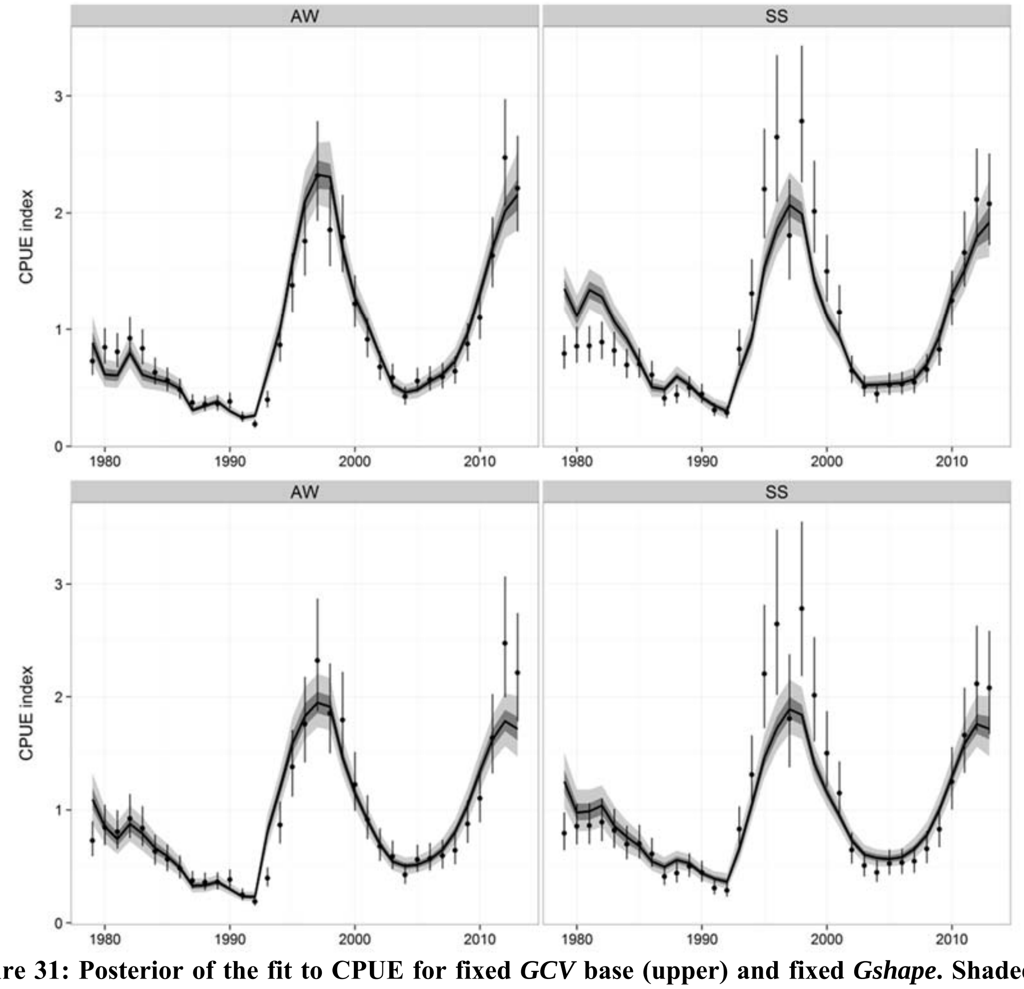


Figure 31: Posterior of the fit to CPUE for fixed *GCV* base (upper) and fixed *Gshape*. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution; the circles show the observed CPUE and the vertical indicate their standard deviation.

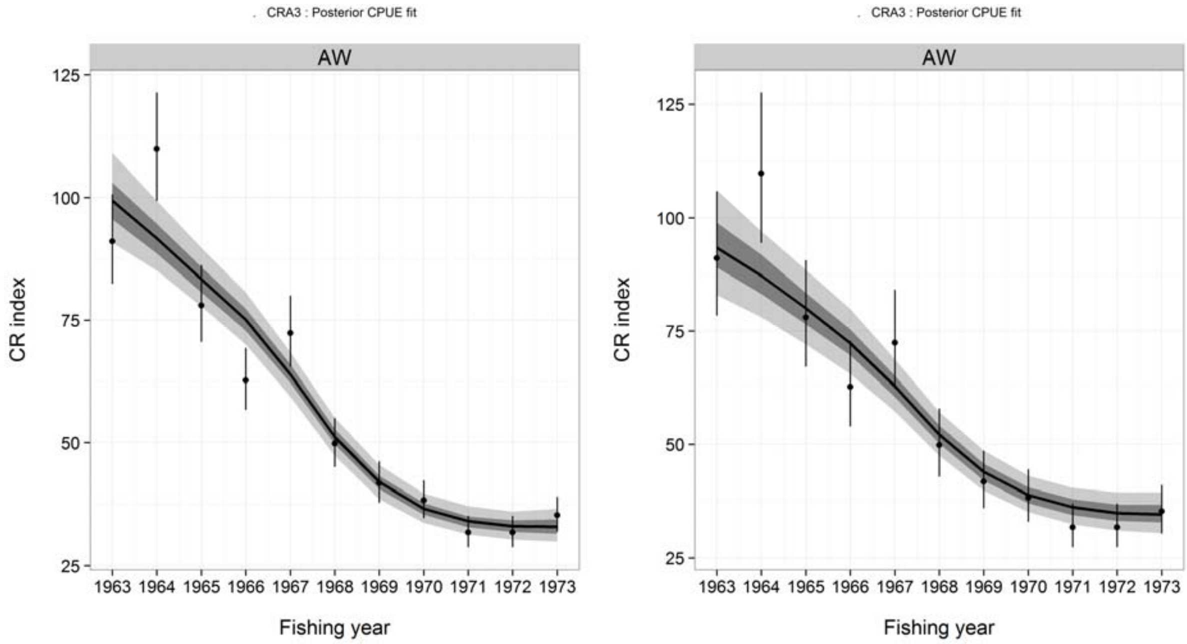


Figure 32: Posterior of the fit to historical catch rate CR for fixed *GCV* base (left) and fixed *Gshape*. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution.

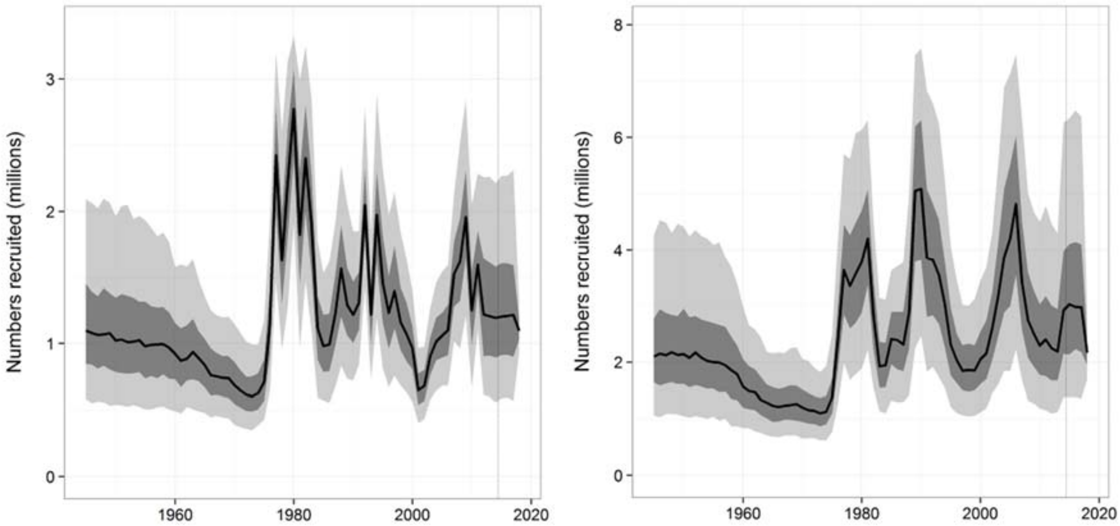


Figure 33: Posterior of the recruitment trajectory for fixed *GCV* base (left) and fixed *Gshape.* Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2013, the final fishing year of the model reconstruction.

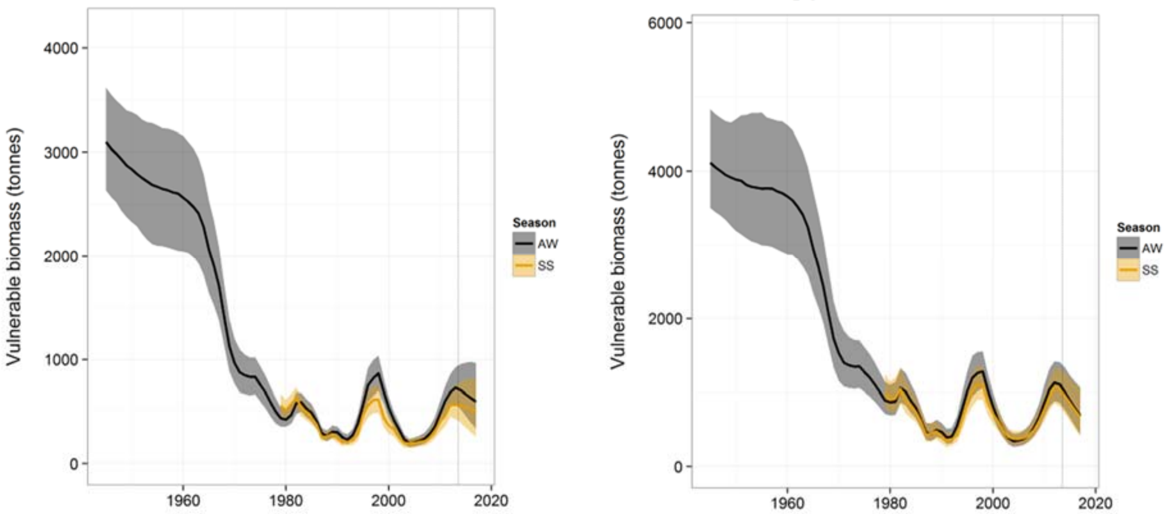


Figure 34: Posterior of the vulnerable biomass trajectory for fixed *GCV* base (left) and fixed *Gshape*. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2013, the final fishing year of the model reconstruction.

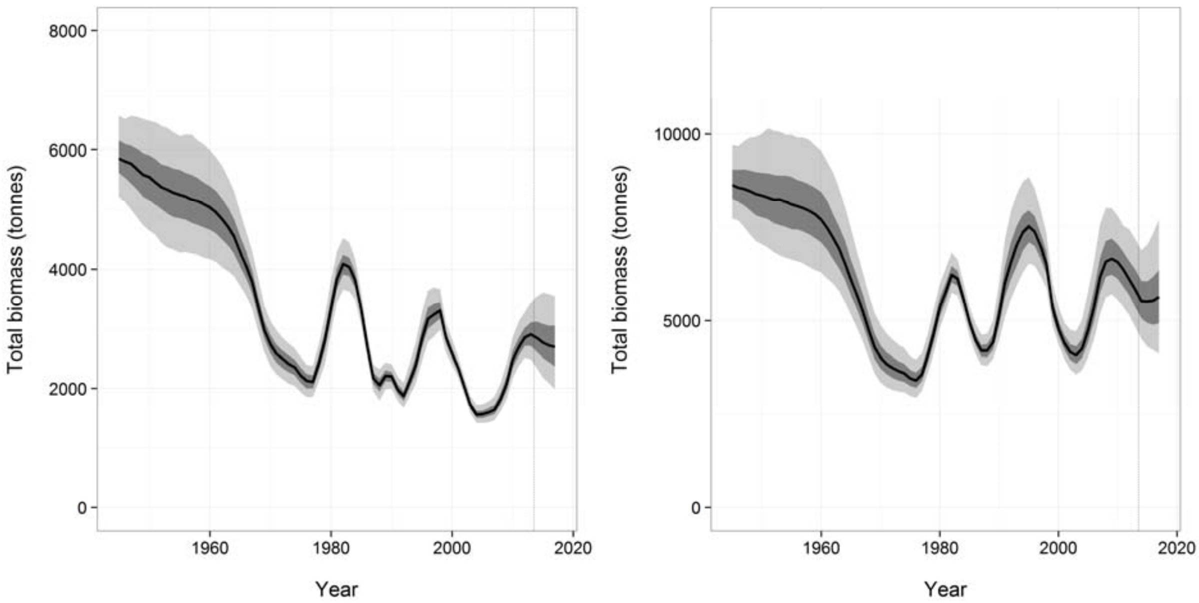


Figure 35: Posterior of the total biomass trajectory for the fixed *GCV* base case (left) and fixed *Gshape*. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2013, the final fishing year of the model reconstruction.

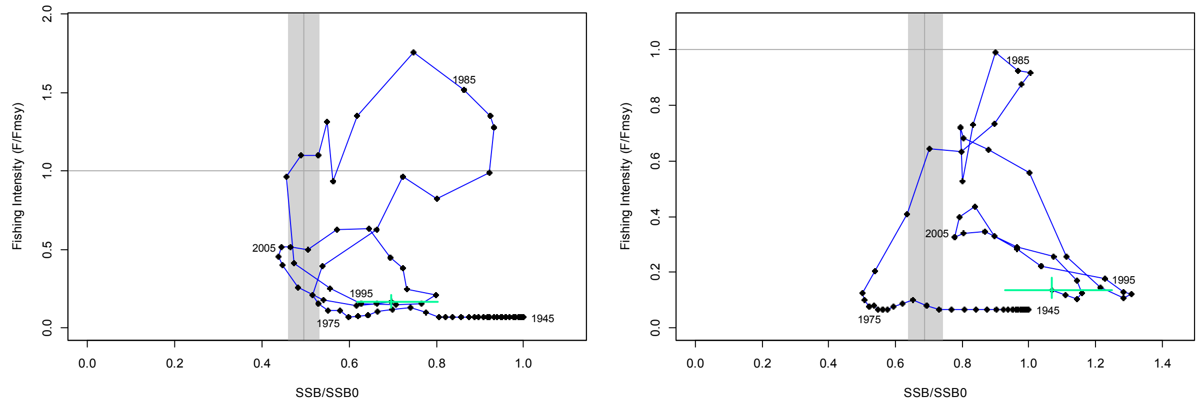


Figure 36: Snail trails from the two base case McMCs: fixed *GCV* on the left, showing the median spawning biomass on the x-axis and median fishing intensity on the y-axis. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock *SSB0*. *SSB0* is constant for all years of a run, but varies among the 1000 samples from the posterior distribution. The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year y; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies every year because the fishing patterns change. It was calculated with a 50-year projection for each year in each run, with the NSL catch held constant at that year's value, deterministic recruitment at R0 and a range of multipliers on the SL catch Fs estimated for year y. The *F* (actually *F*s for two seasons) that gave MSY was *Fmsy*, and the multiplier was *Fmult*. Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

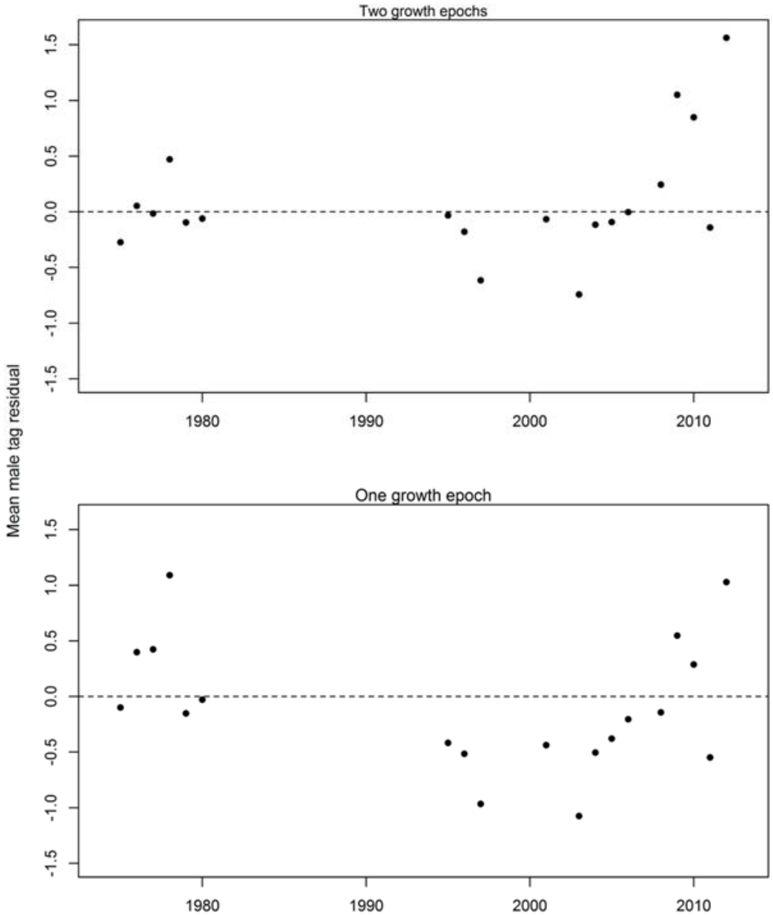


Figure 37: Mean residuals by year from the fit to male tags from the second tag file in the fixed *GCV* base case (upper) and from a fit to a single combined tag set with fixed *GCV*; the dotted line shows zero.

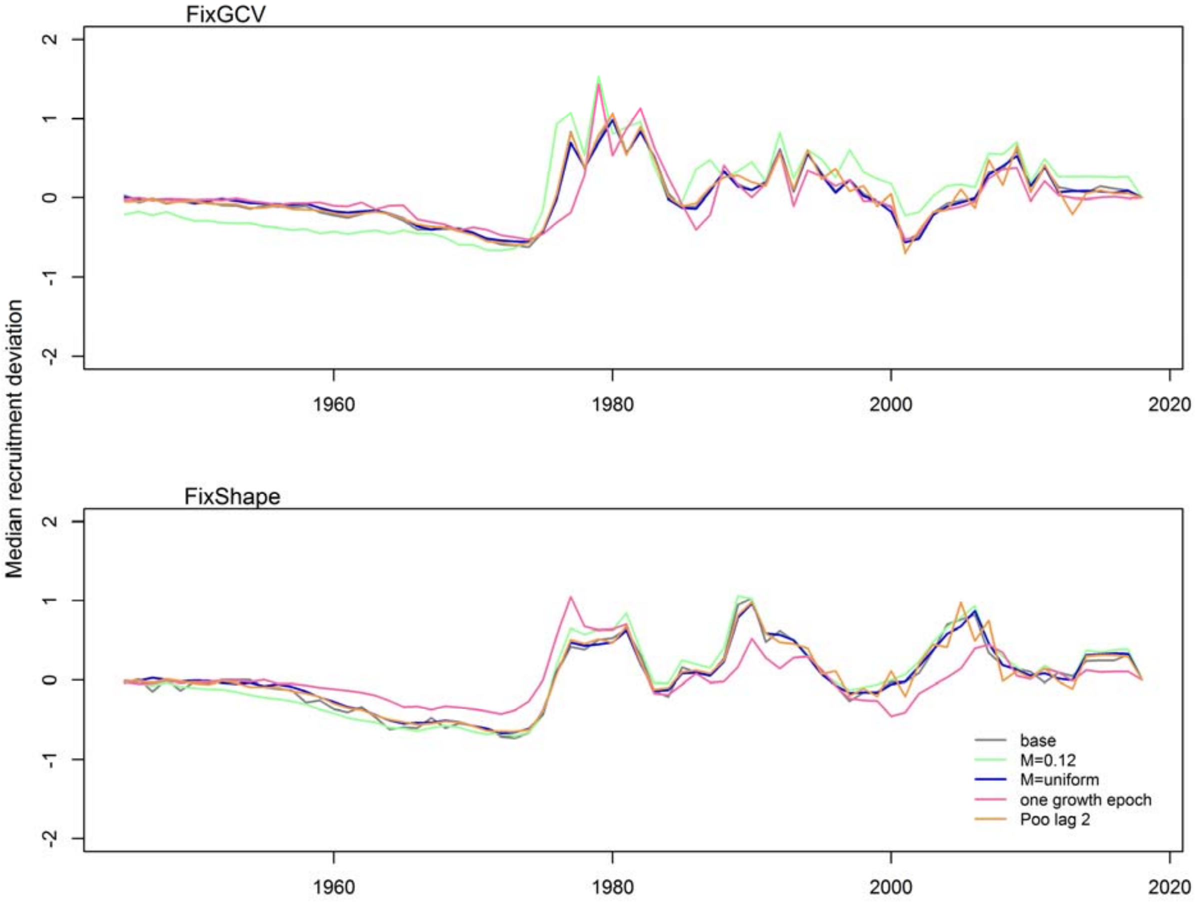


Figure 38: Median *Rdev* trajectories from the McMC base cases and sensitivity trials, with fixed *GCV* base case on the upper figure.

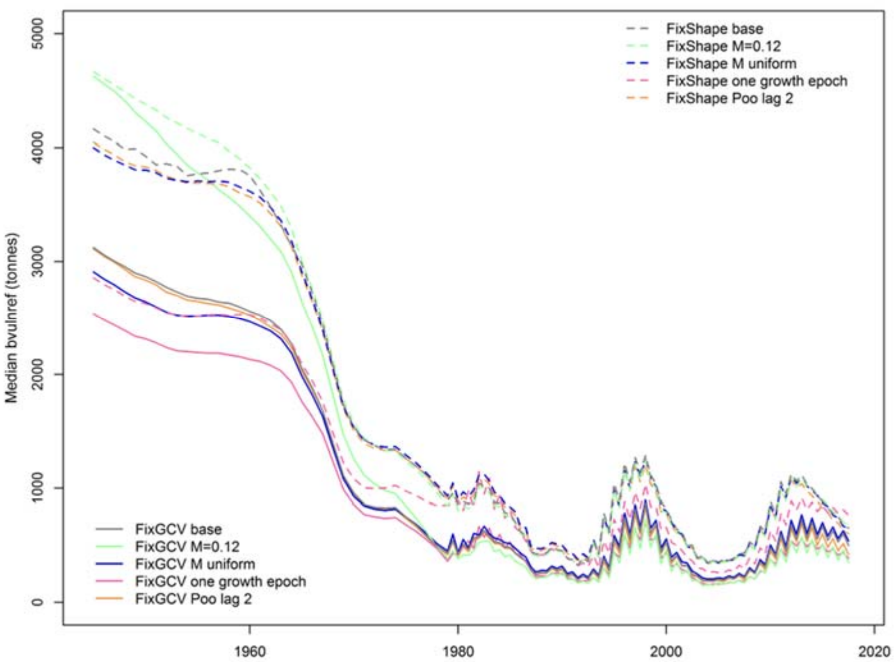


Figure 39: Median vulnerable biomass trajectories from the base case McMCs and the McMC sensitivity trials; the fixed *GCV* runs are solid lines and the fixed *Gshape* runs are dashed lines.

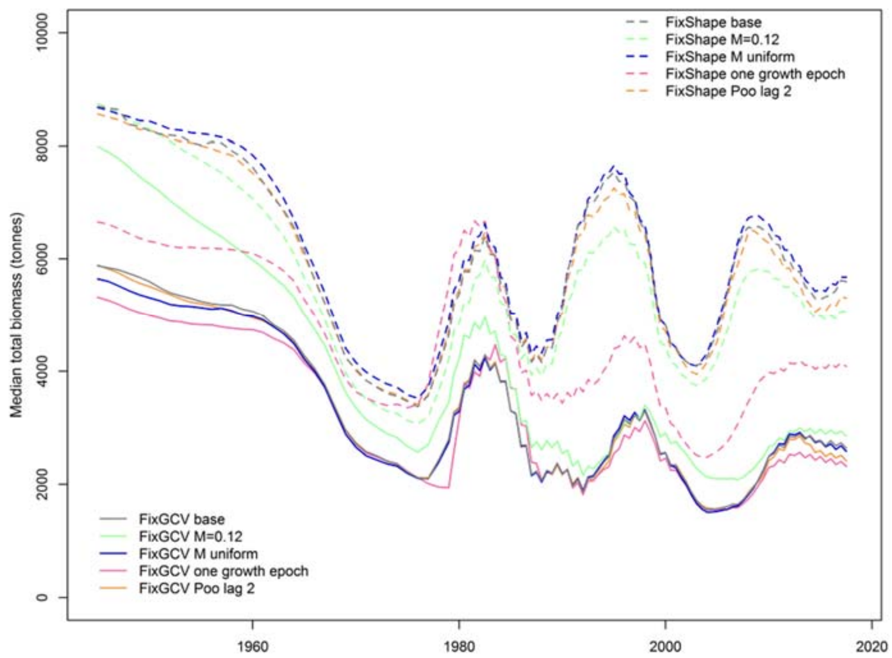


Figure 40: Median *Btotal* trajectories from the base case McMCs and the McMC sensitivity trials; the fixed *GCV* runs are solid lines and the fixed *Gshape* runs are dashed lines.

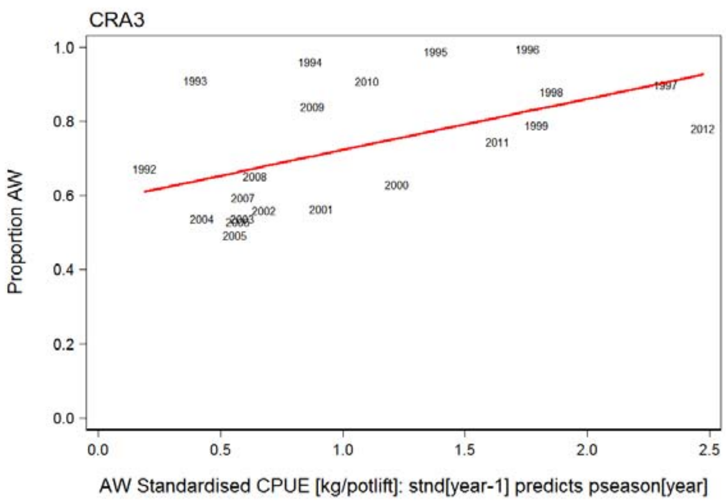


Figure 41: Proportion of catch taken in AW vs. AW standardised CPUE; the solid line shows the fit regression.

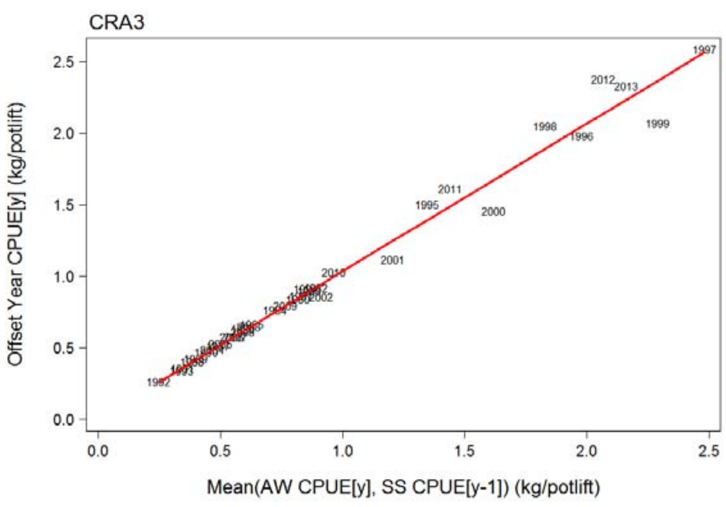


Figure 42: Observed offset-year CPUE for 1980–2013 vs. the average of AW and SS seasonal CPUE over the same period; the solid line shows the fit regression.

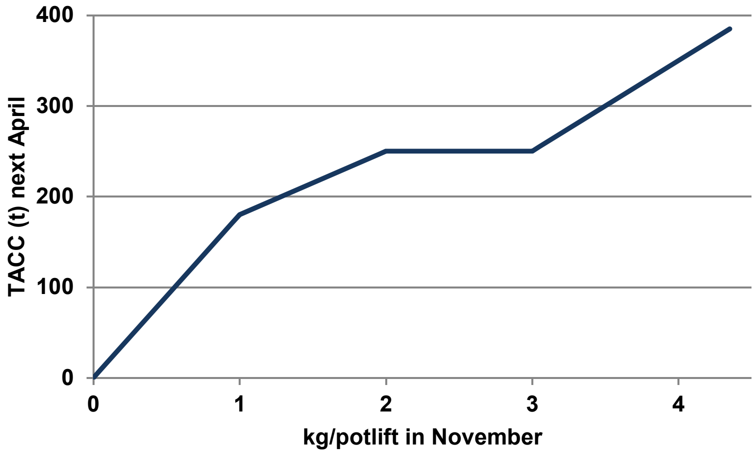


Figure 43: Harvest control rule requested by CRA 3 industry, with two slope sections to the left of the plateau.

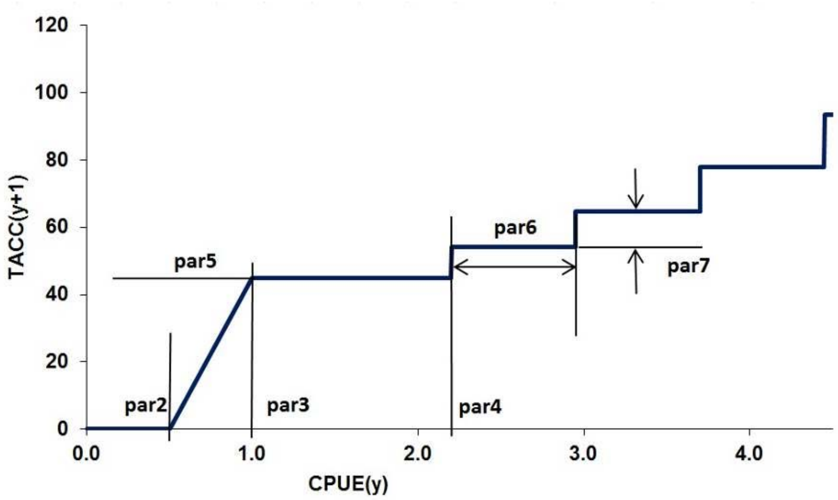


Figure 44: A generalised plateau step rule (rule type 4).

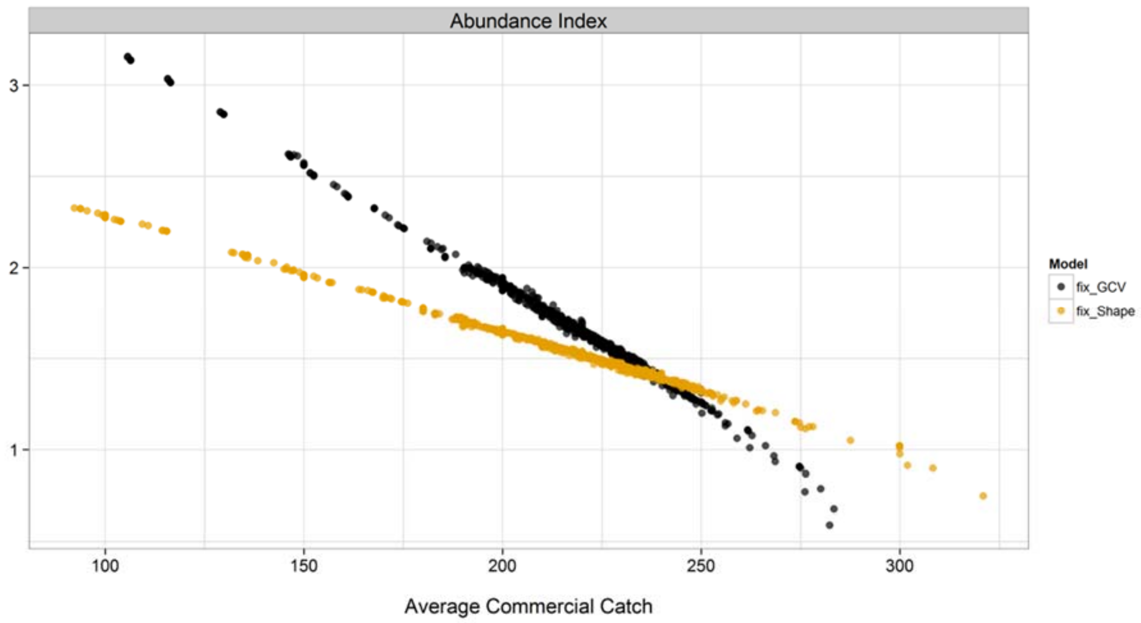


Figure 45: Average CPUE vs. average commercial catch in a large set of type 4 rules: each point shows the average from 1000 simulations of a rule, black points are from the fixed *GCV* base case and coloured from the fixed *Gshape* base case.

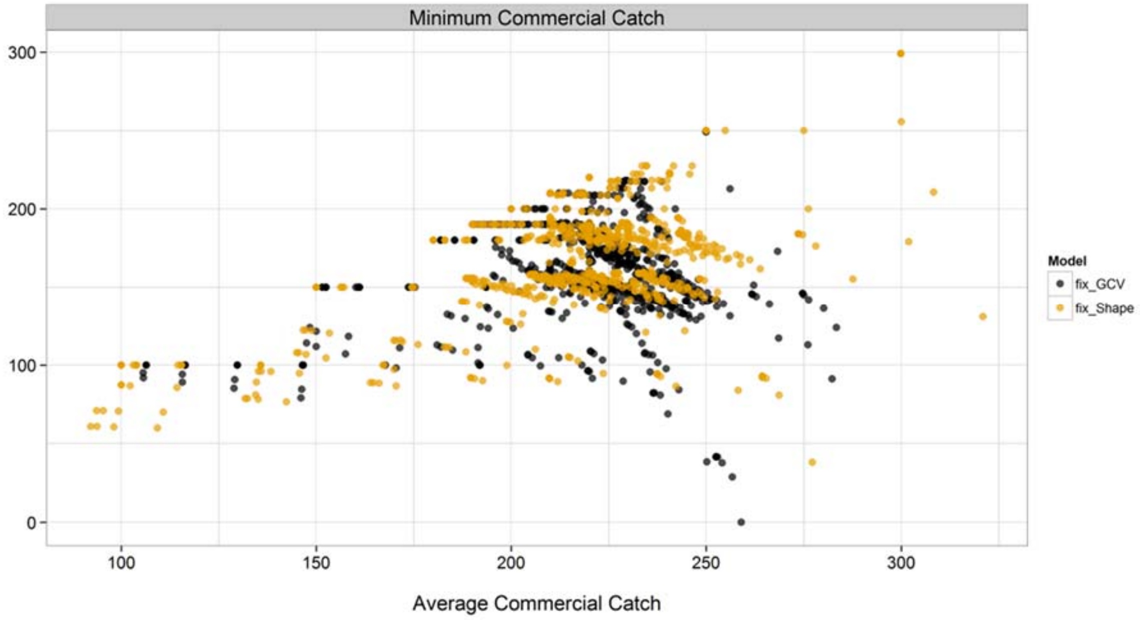


Figure 46: Minimum vs. average commercial catch in a large set of type 4 rules each point shows the average from 1000 simulations of a rule, black points are from the fixed *GCV* base case and coloured from the fixed *Gshape* base case.

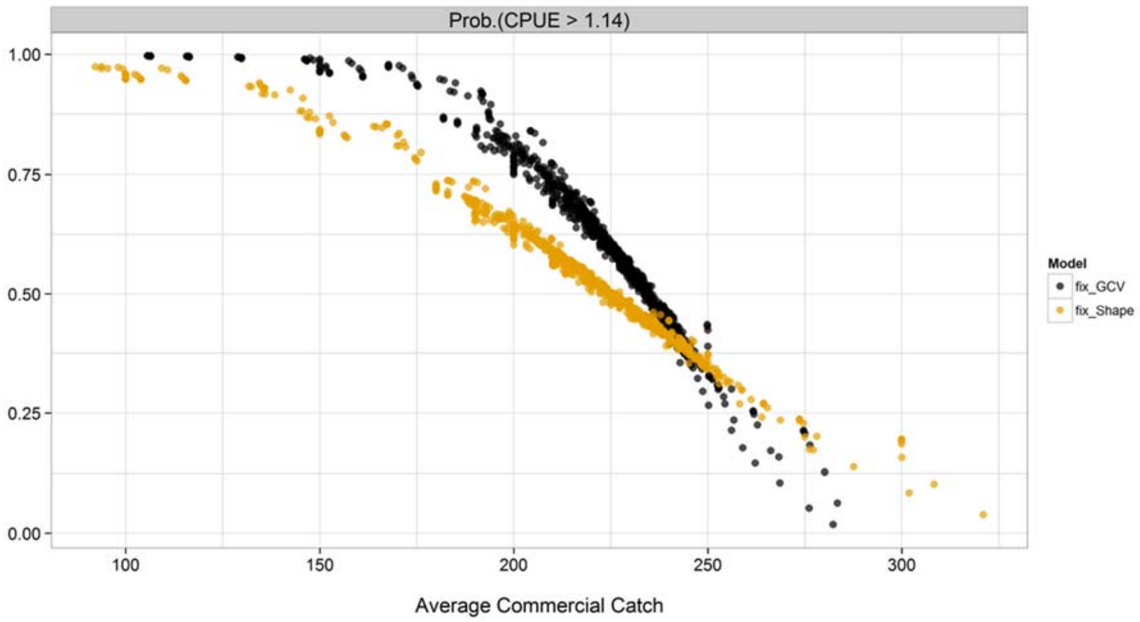


Figure 47: Probability that CPUE exceeds 1.14 vs. average commercial catch in a large set of type 4 rules; black points are from the fixed *GCV* base case and coloured from the fixed *Gshape* base case.

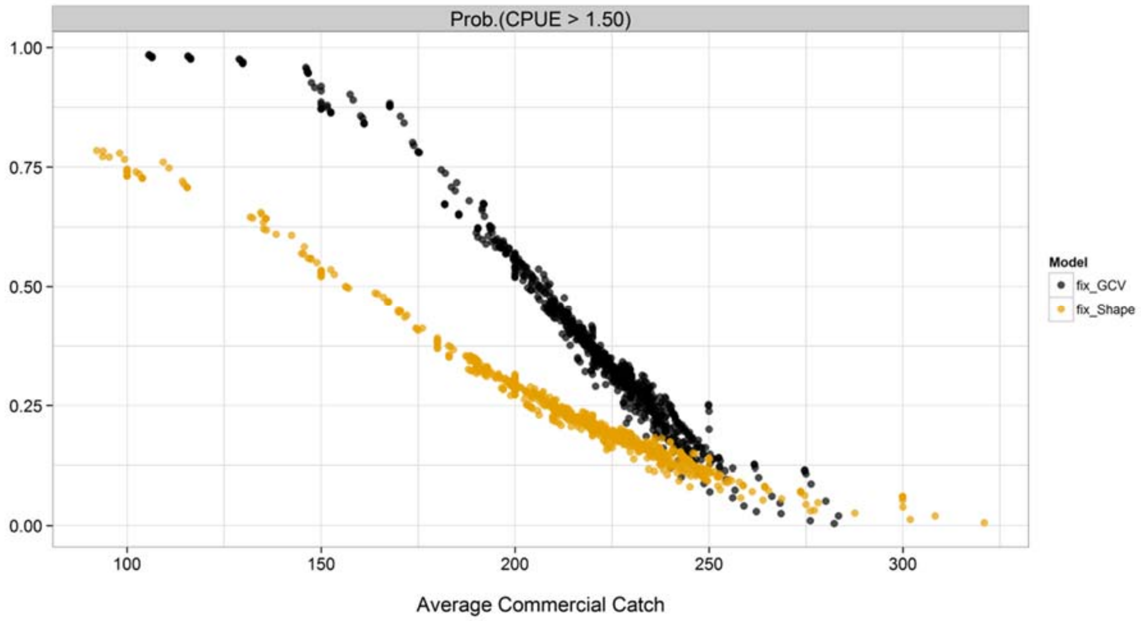


Figure 48: Probability that CPUE exceeds 1.50 vs. average commercial catch in a large set of type 4; black points are from the fixed *GCV* base case and coloured from the fixed *Gshape* base case.

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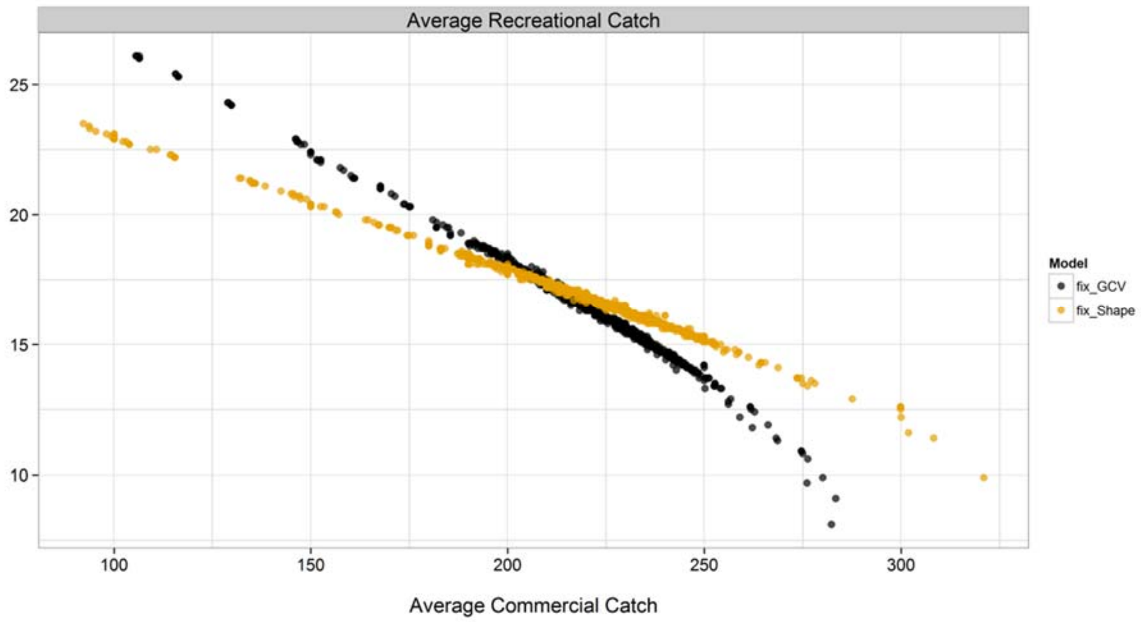


Figure 49: Average recreational vs. average commercial catch in a large set of type 4 rules; black points are from the fixed *GCV* base case and coloured from the fixed *Gshape* base case.

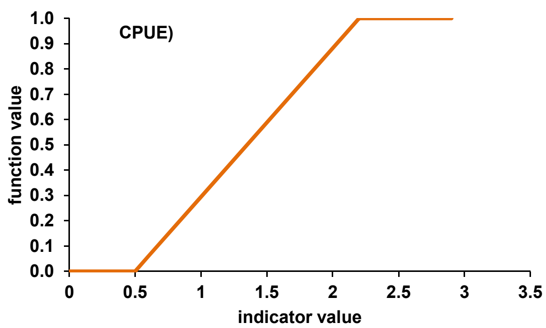


Figure 50: Utility function for CPUE; the two parameters are 0.5 and 2.2 kg/potlift.

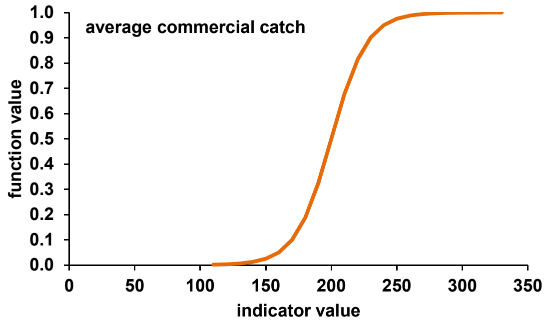


Figure 51: Utility function for commercial catch; the two parameters for the logistic are 200 t and 40 t.

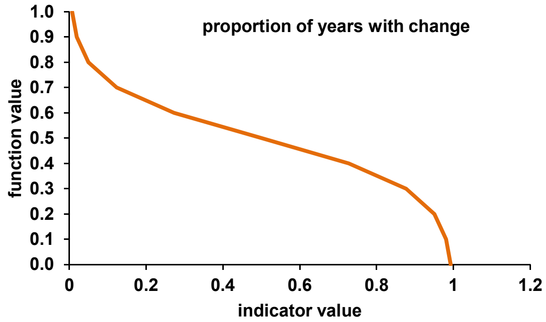


Figure 52: Utility function for proportion of years with TACC change; the two parameters for the logistic are 0.5 and 0.3.

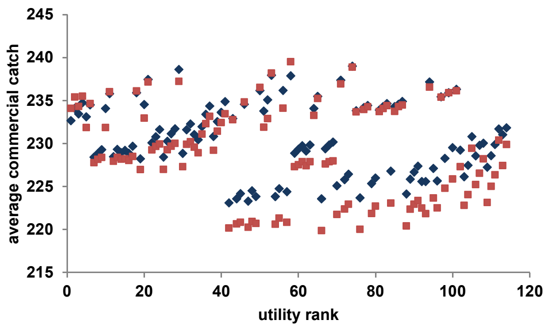


Figure 53: Average commercial catch vs. rank on the utility score for 114 screened rules; blue diamonds are from fixed *GCV* base case and red squares from the fixed *Gshape* base case.

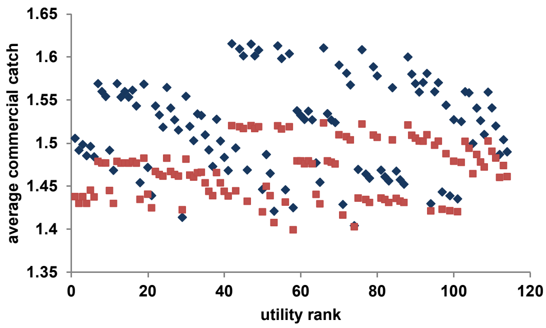


Figure 54: Average CPUE vs. rank on the utility score for 114 screened rules; blue diamonds are from fixed *GCV* base case and red squares from the fixed *Gshape* base case.

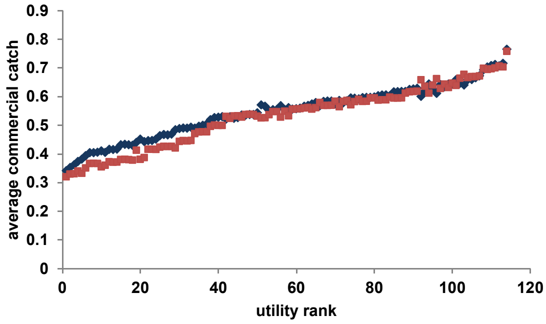


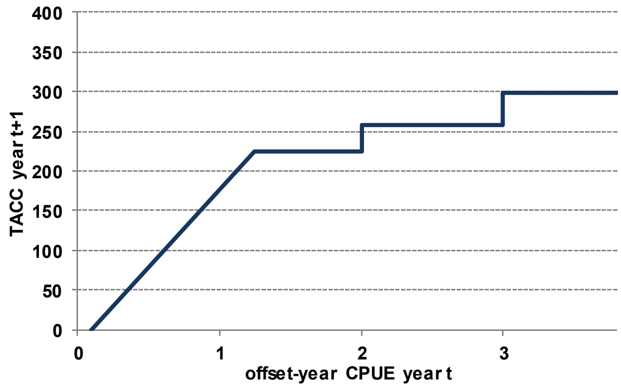
Figure 55: CRA 3: Proportion of years with TACC change vs. rank on the utility score for 114 screened rules; blue diamonds are from fixed *GCV* base case and red squares from the fixed *Gshape* base case.

	rule type	intercept	plateau left	plateau right	plateau height	step width	step height	min change	max change	latent year
rule	par1	par2	par3	par4	par5	par6	par7	par8	par9	par10
	4	0.1	1.25	2	225	1	0.15	0.05	0	0

index

6

VP03a/05



base1 fixed *GCV*
base2 fixed *Gshape*
R1 low recruitmentt
R2 high CPUE noise
R3 OneGrowth
R4 *M* = 0.12

	base1	base2	R1_1	R1_2	R2	R3	R4
minimum commercial catch	153.1	156.3	96.7	65.8	120.4	171.3	132.8
average commercial catch	223.6	219.3	181.7	147.1	219.1	226.2	213.8
minimum recreational catch	11.9	12.8	8.6	6.6	12.4	12.5	12.3
average recreational catch	16.2	16.9	11.9	10.1	16.6	16.5	15.3
minimum CPUE	0.875	0.892	0.588	0.430	0.708	0.960	0.773
average CPUE	1.606	1.526	1.102	0.878	1.626	1.679	1.466
AAVH%	8.10	7.61	16.42	17.93	15.67	7.69	10.25
years with TACC change	49.7%	48.9%	70.2%	76.4%	67.5%	47.9%	55.5%
P(B<Bmin)	0.4%	0.6%	5.6%	30.8%	0.7%	0.8%	1.6%
P(B<Bmsy)	1.0%	0.0%	8.4%	3.7%	0.6%	4.4%	0.3%
P(left of plateau)	28.2%	31.6%	67.3%	82.4%	33.5%	23.4%	38.3%
P(right of plateau)	24.4%	18.0%	6.3%	2.8%	27.1%	29.0%	18.8%
P(CPUE in AW > 1.14)	61.9%	53.9%	22.7%	9.7%	59.4%	64.2%	50.8%
P(CPUE in AW > 1.50)	33.9%	21.1%	8.6%	1.7%	28.2%	36.0%	25.1%

CPUE 2.214 259

Figure 56: Output from the rule viewer for one harvest control rule (rule 6) sent to consultation by the NRLMG.

	rule type	intercept	plateau left	plateau right	plateau height	step width	step height	min change	max change	latent year
rule	**par1**	**par2**	**par3**	**par4**	**par5**	**par6**	**par7**	**par8**	**par9**	**par10**
	6	0	0	0	260	0	0	0.05	0	0

index

4

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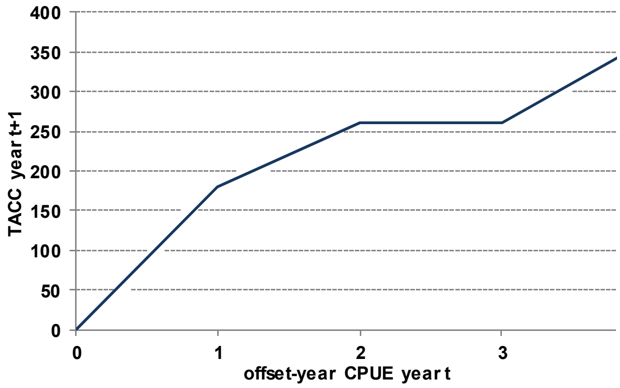

base1 fixed *GCV*
base2 fixed *Gshape*
R1 low recruitmentt
R2 high CPUE noise
R3 OneGrowth
R4 *M* = 0.12

	base1	base2	R1_1	R1_2	R2	R3	R4
minimum commercial catch	162.8	163.2	106.4	75.2	128.9	169.4	142.8
average commercial catch	223.8	219.3	181.8	150.2	220.1	227.2	213.4
minimum recreational catch	12.1	12.8	8.5	6.4	12.4	12.5	12.3
average recreational catch	16.2	16.9	11.9	9.9	16.6	16.4	15.3
minimum CPUE	0.893	0.898	0.582	0.411	0.707	0.960	0.787
average CPUE	1.600	1.527	1.102	0.864	1.623	1.659	1.462
AAVH%	8.12	8.10	13.80	15.28	16.07	7.79	9.63
years with TACC change	61.3%	62.8%	74.7%	78.6%	75.6%	58.6%	65.9%
P(B<Bmin)	0.4%	0.6%	5.9%	33.4%	0.7%	0.7%	1.7%
P(B<Bmsy)	0.9%	0.0%	8.8%	5.1%	0.6%	4.3%	0.3%
P(left of plateau)	76.7%	82.3%	93.9%	97.3%	73.5%	72.7%	81.8%
P(right of plateau)	2.6%	1.5%	0.4%	0.1%	5.8%	3.3%	2.4%
P(CPUE in AW > 1.14)	62.1%	54.1%	22.5%	9.3%	58.9%	63.3%	50.7%
P(CPUE in AW > 1.50)	32.3%	20.5%	8.3%	1.6%	27.5%	33.9%	24.3%

CPUE 2.2139 260

Figure 57: Output from the rule viewer for the other harvest control rule sent to consultation by the NRLMG (rule 4).

GLOSSARY

This glossary is intended to make the rock lobster stock assessment and MP development processes more accessible to non-technical readers. A knowledge of statistical terms is assumed and such terms are not explained here. Technical terms are defined with specific reference to rock lobster stock assessment and the multi-stock length-based model (MSLM) and may not be applicable in other contexts.

Underlining indicates a cross-reference to a separate entry.

abundance index: usually a time-series of estimates of abundance in numbers or weight (biomass).

AD Model Builder: a modelling package widely used in fisheries work; it uses auto-differentiation to calculate the derivatives of the function value with respect to model parameters and passes these to an efficient minimiser; the user has to write only the model and calculate the function value.

allowance: the Minister must make Allowances for catch from various sectors within the TAC; the TACC and other allowances must sum to the TAC.

AW: autumn-winter season, 1 April through 30 September; see SS.

***B0*:** the biomass that would be attained if there were no fishing and recruitment were constant at its average level; in the MSLM the initial biomass is *B0.*

Bayesian stock assessment: a method that allows prior independent information to be used formally in addition to the data; the equivalent of the least-squares or maximum likelihood estimate is called the MPD (mode of the joint posterior distribution); often uncertainty is estimated using Markov chain Monte Carlo simulations (McMC) which give the posterior distributions of estimated and derived parameters.

***Bcurrent*:** the MSLM estimate of vulnerable biomass in the last year with data.

biomass: the weight of fish in part of the stock.

biological reference points: a target for the fishery or a limit to be avoided, or that invokes management action; expressed quantitatively, usually in units of fishing intensity or stock size.

***Bmin*:** the minimum of estimated vulnerable biomass in the years for which MSLM estimates biomass.

***Bmsy*:** in the *MSY* paradigm, the biomass that allows the stock to generate its maximum productivity; this biomass is usually less than half the unfished biomass.

bounds: model parameters can be restricted so that parameter estimates cannot be less than a lower bound or higher than an upper bound; these are sometimes necessary to prevent mathematical impossibility (e.g. a proportion must be between 0 and 1 inclusive) or to ensure biologically realistic model results.

***Bproj* :** vulnerable biomass in the last projection year, determined by running the model dynamics forward with specified catches and resampled recruitment.

***Bvuln*:** see vulnerable biomass.

catch: the numbers or weight (yield) of fish removed from the stock by fishing in a season or a year; considered in components such as commercial and illegal catches, or together as total catch; does not include fish returned alive to the sea.

catchability: a proportionality constant that relates an abundance index such as CPUE or CR to biomass, or that relates the puerulus settlement index to numbers; has the symbol *q*.

catch sampling: see logbooks and observer catch sampling.

cohort: a group of lobsters that settled in the same year.

converged chain: refers to McMC results; the "chain" is the sequence of parameter estimates; convergence means that the average and the variability of the parameter estimates are not changing as the chain gets longer.

CPUE: catch per unit of effort; has the units kg of catch per potlift; assumed to be an abundance index such that CPUE = catchability times vulnerable biomass; can be estimated in several ways (see standardisation).

CPUEpow: a parameter that determines the shape of the relation between CPUE and biomass; when equal to 1, the relation is linear; when less than 1, CPUE decreases less quickly than biomass (known as hyperstability); when greater than 1, CPUE decreases faster than biomass (known as hyperdepletion).

CR: an historical CPUE abundance index in kilograms per day from 1963–73.

customary fishing: fishing under permit by Maori for purposes associated with a marae; there is more than one legal basis for this.

density-dependence: populations are thought to self-regulate: as population biomass increases, growth might slow down, mortality increase, recruitment decrease or maturity occur later; growth is density-dependent if it slows down as the biomass increases.

derived parameter: any quantity that depends on the model's estimated parameters; e.g. average recruitment *R0* is an estimated parameter but initial biomass is a derived parameter that is determined by model parameters for growth, natural mortality and recruitment.

diagnostic plots: plots of running or moving statistics based on the McMC chains to check for convergence.

epoch: a period when selectivity was constant; different epochs have different estimated selectivity; epoch boundaries are associated with changes that affect selectivity, e.g. changes in escape gaps or MLS.

escape gaps: openings in the pot that allow small lobsters an opportunity to escape.

equilibrium: in models, a stable state that is reached when catch, fishing patterns, recruitment and other biological processes are constant; does not occur in nature.

exploitation rate: a measure of fishing intensity; catch in a year or period divided by initial biomass; symbol *U*.

explanatory variable: information associated with catch and effort data (e.g., month, vessel, statistical area or fishing year) that might affect CPUE; the standardisation procedure can identify patterns associated with explanatory variables and can relate changes in CPUE to the various causes.

***F*:** instantaneous rate of fishing mortality.

fishing intensity: informal term with no specific definition; higher fishing intensity involves higher fishing mortality or higher exploitation rate, or (as in the snail trial) a higher ratio of *F* to *Fmsy*.

fishing mortality: (symbol *F*) the instantaneous rate of mortality caused by fishing; if there were no natural mortality or handling mortality, survival from fishing would be e^{-F}; with fishing and natural mortality, survival is $e^{-(F+M)}$.

fishing pattern: the combination of selectivity and the seasonal distribution of catch.

fishing year: for rock lobsters, the year from 1 April through 30 March; often referred to by the April to December portion, *i.e.* 2009–10 is called "2009".

fixed parameter: a parameter that could be estimated by the model but that is forced to remain at the specified initial value.

Fmsy: the instantaneous fishing mortality rate *F* that gives *MSY* under some simplistic constant conditions.

function value: given a set of parameters, how well the model fits the data and prior information; determined by the sum of negative log likelihood contributions from each data point and the sum of contributions from the priors; a smaller value reflects a better fit.

growth: lobsters grow when they moult; smaller lobsters do this more often than larger lobsters; the model assumes a continuous growth process described by a flexible growth sub-model that predicts mean growth increment for a time step based on sex and initial size, and predicts the variability of growth around this mean.

***growthCV* :** determines the expected variability in growth around the mean increment for a given initial size.

harvest control rule: defines what the agreed management response will be at each observed level of the stock; often a mathematical relation between an observed index such as CPUE and the allowable catch.

Hessian matrix: a matrix of numbers calculated by the model using formulae based on calculus, then used to estimate variances and covariances of estimated parameters; if the matrix is well-formed it is "positive definite" and the model run is said to be "pdH".

hyperdepletion: see *CPUEpow.*

hyperstability: see *CPUEpow.*

indicators: generic term for agreed formal outputs that act as the basis for the stock assessment or MPE comparisons.

initial value: when the model minimises, it has to start with a parameter set and the initial values comprise this set; the final estimates should be robust to the arbitrary selection of the initial values.

length frequency (LF) (also called size frequency)**:** The distribution of numbers-at-size (TW) from catch samples; based either on observer catch sampling or voluntary logbooks; the raw data are compiled with a complex weighting procedure.

length-based: a stock assessment using a model that keeps track of numbers-at-size over time.

likelihood contribution: for the model's fit to a data set, there is a calculated negative log likelihood for each data point; the contribution to the function value for a dataset is the sum of all these; this approach to fitting data is based on maximum likelihood theory.

logbooks: in some areas, fishers tag four or five pots and when they lift one of these they measure all the lobsters and determine sex and female maturity; these data are a source of LFs for stock assessment; see also observer catch sampling.

***M*:** instantaneous rate of natural mortality.

management procedure: more properly "operational management procedure"; a set of rules that specify an input and how it will be determined, a harvest control rule and the conditions under which it will operate; a special form of decision rule because it has been extensively simulation tested.

MAR: median of the absolute values of residuals for a dataset. In a good estimation with multiple data sets, this should be close to 0.7; a common procedure is to weight datasets to try to obtain MAR close to 0.7.

maturity: the ability to reproduce; it is determined in catch sampling (for females only), by observing whether the abdominal pleopods have long setae.

maturation ogive: the relation between female size and the probability that an immature female will become mature in the next specified time step.

McMC: Markov chain – Monte Carlo simulations. In the minimisations, the model uses a mathematical procedure to find the set of parameters that give the best (smallest) function value. McMC simulations randomly explore the combinations of parameters in the region near the "best" set of parameters, using a sort of random walk, and from this the uncertainty in estimated and derived parameters can be measured. In one "simulation", the algorithm generates a new parameter set, calculates the function value and chooses whether to accept or reject the new point.

MFish: the New Zealand Ministry of Fisheries (now part of the Ministry for Primary Industries, MPI).

mid-season biomass: biomass after half the catch has been taken and half the natural mortality has acted in the time step.

minimising: the model fits to data are determined by estimated parameters, and the goodness of fit can be measured in terms of the model's function value, where a lower value reflects a better fit; when minimising, the model adjusts parameter values to try to reduce the function value, using a mathematical approach based on calculus.

MLS: minimum legal size; currently 54 mm TW for males and 60 mm TW for females for most of New Zealand, but some QMAs have different MLS regimes.

mortality: processes that kill lobsters; see natural mortality *M* and fishing mortality *F*; handling mortality of 10% is assumed for lobsters returned to the sea by fishing.

MPD: when the model is minimising, the result is the set of parameter estimates that give the lowest function value; these "point estimates" comprise the mode of the joint posterior distribution or MPD; also sometimes called maximum posterior density.

MPEs: management procedure evaluations; for each proposed harvest control rule, a run is made from each sample of the joint posterior distribution, indicators are calculated and collated, and a set of indicators for that rule with that operating model (which might be the base case or one of the robustness trials) is generated.

MPI: Ministry for Primary Industries (formerly Ministry of Fisheries or MFish).

MSY: under the MSY paradigm, the maximum average catch that can be taken sustainably from the stock under constant environmental conditions; usually calculated under simplistic assumptions.

MSY paradigm: a simplistic interpretation that predicts surplus production as a function of biomass: with zero surplus production at zero biomass, zero surplus production at carrying capacity (symbol *K*), and a maximum production at some intermediate biomass in between; this ignores the effects of age and size structure, lags in recruitment and variability in production that is unrelated to biomass.

MSLM: multi-stock length-based model; current version of the stock assessment model: length-based, Bayesian, with capacity for assessing multiple stocks simultaneously.

natural mortality: (symbol *M*) the instantaneous rate of mortality from natural causes. If there were no fishing mortality *F*, survival would be e^{-M}. With both fishing and natural mortality, survival is $e^{-(F+M)}$.

Newton-Raphson iteration: the model dynamics need a value for fishing mortality rate *F* in each time step; MSLM has information about catch, biomass and *M*, but there is no equation that can give *F* directly from these; Newton-Raphson iteration begins with an arbitrary value for *F* and calculates catch, then refines the value for *F* using a repeated mathematical approach based on calculus to obtain the *F* value that is correct.

normalised residual: the residual divided by the standard deviation of observation error that is assumed or estimated in the minimising procedure.

NRLMG: National Rock Lobster Management Group, a stakeholder group comprising representatives from MPI, commercial, customary and recreational sectors, that provides rock lobster management advice to the Minister for Primary Industries.

NSL catch: catch taken without regard to the MLS and prohibition on egg-bearing females; assumed by the model to be the illegal and customary catches; note that NSL catch includes fish above the MLS.

observer catch sampling: catch sampling in which an observer on a vessel measures all the fish in as many pots as possible on one trip.

offset year: the year from 1 October through 30 September, six months out of phase with the rock lobster fishing year.

operating model: a simulation model that represents the stock and that can be projected forward to test the results of using alternative harvest control rules.

parameters: in a simulation model, numbers that determine how the model works (they define mortality and growth rates, for instance) and that can be estimated during fitting to data or minimising.

pdH: see Hessian matrix.

period: sequential time steps (years or seasons or a mixture of both) in the stock assessment model.

population: in nature, a group of fish that shares common ecological and genetic features; in models, the numbers of fish contained in a stock unit within the model.

posterior distribution: the distribution of parameter estimates resulting from McMC simulation; is a Bayesian concept; the posterior distribution is a function of the prior probability distribution and the likelihood of the model given the data.

potlift: a unit of fishing effort; the commercial fishery uses traps or pots baited to attract lobsters and equipped with escape gaps; pots are sometimes lifted daily, often less frequently because of weather or markets; pots are often moved around during the fishing year.

pre-recruit: a fish that has not grown large enough (to or past the MLS) to become vulnerable to the fishery.

priors: short for prior probability distribution; these allow the modeller to estimate parameter values using Bayes's theorem and (if desired) to incorporate prior belief (based on data that are not being used by the model) about any likely parameter values.

productivity: stock productivity is a function of fish growth and recruitment, natural mortality and fishing mortality.

projections: given a set of parameters, assumed catches and recruitments, the stock assessment model or operating model dynamics can be run into the future and any indicators calculated that are wished; this is called projecting the model; projections are sometimes thought of as predictions but, more properly, projections determine the range of values in which parameters about the future stock may lie.

puerulus: settling lobster larvae; this stage is transitional between the planktonic phyllosoma larva and the benthic juvenile lobster; in reality the puerulus settlement index includes juveniles of the first instars. The puerulus settlement index for a stock is calculated from monthly observations of settlement on sets of collectors within the QMA, using a standardisation method.

QMA: A management unit in the Quota Management System, which in most cases is assumed to represent the extent of the biological stock; the unit of management in the quota management system; QMAs contain smaller statistical areas.

QQ plots: in an estimation where the data fit the model's assumptions about them, the normalised residuals would follow a normal distribution with mean zero and standard deviation of one; a QQ plot allows a comparison of the actual and theoretical distributions of normalised residuals by plotting the observed quantiles in a way that gives a straight line if they follow the theoretical expectations.

***R0* :** the base recruitment value in numbers of fish.

randomisation: in the puerulus randomisation trials, a new index is generated by randomly rearranging the yearly values data in a new order.

Rdevs: estimated model parameters that determine whether recruitment in a given year is above or below average; they modify the base recruitment parameter *R0.*

recreational: refers to catch taken legally under the recreational regulations; includes s. 111 catch taken by commercial fishers; includes Maori fishing that is not governed by a customary permit.

recruited biomass: the weight of all fish above the MLS, including egg-bearing females, whether or not they can be caught by the fishery.

recruitment: can mean recruitment to the population (as in puerulus settlement), recruitment to the model at a specified size, or recruitment to the stock (by growing above MLS); when used with no qualification in documentation here it means "recruitment to the model".

resampling: in projections, recruitment for a projection year is equal to estimated recruitment in a randomly chosen year that lies within the range of years being resampled.

residual: the observed data value minus the model's predicted value, for instance for CPUE in a given time step it would be the difference between the observed CPUE in that year and the model's predicted value.

RLFAWG (Rock Lobster Fishery Assessment Working Group): a group convened by MPI to discuss stock assessment alternatives and to act as peer-reviewers; comprises MPI, stakeholders and contracted peer-reviewers.

robustness trial: in making MPEs, the sensitivity of results to critical assumptions in the operating model is tested by making runs in robustness trials using a different operating model.

sdnr: the standard deviation of normalised residuals; in a good estimation with multiple data sets, this should be close to 1; a common procedure is to weight datasets to try to obtain sdnrs close to 1.

season: refers to the AW or SS seasons; for early years the MSLM model can be run with an annual time step.

selectivity: lobster pots do not catch very small lobsters; selectivity describes the relative chance of a lobster being caught, given its sex and size, hence "selectivity ogive".

sensitivity trials: a base case stock assessment model is the result of inevitable choices made by the modeller; sensitivity trials examine whether results are seriously dependent on ("sensitive to") these choices.

sex: in the model can be male, immature female or mature female; this set of three possibilities is referred to as "sex" (see maturity).

snail trail: a plot of historical fishing intensity against historical biomass.

SL catch: the catch that is taken respecting the MLS and prohibition on egg-bearing females; assumed by the model to be the commercial and recreational catches.

spawning stock biomass: *SSB***,** the weight of all mature females in the AW, without regard to MLS, selectivity or vulnerability; three specific forms are *SSBcurrent*, the estimated *SSB* in the last year with data; *SSBO*, the *SSB* in the first model year; *SSBmsy*, the *SSB* at equilibrium *Bmsy.*

SS: spring-summer season, 1 October through 30 March; see AW.

standardisation: a statistical procedure that extracts patterns in catch and effort data associated with explanatory variables; the pattern in the time variable (e.g. period or year) is interpreted as an abundance index.

statistical area: sub-area of a QMA that is identified in catch and effort data; the most detailed area information currently available from catch and effort data for rock lobster.

stock: by definition, a group of fish inhabiting a quota management area QMA; may often not coincide with biological population definitions.

stock assessment: an evaluation of the past, present and future status of the stock; a computer modelling exercise using a model such as MSLM that is minimised by fitting to observed fishery data; the results include estimated biomass and other trajectories; a comparison of the current stock size and fishing intensity with biological reference points ("stock status"), and often involves short-term projections with various catch levels.

stock-recruit relation: a relation between biomass and recruitment, with low recruitment at lower biomass; an optional component of MSLM.

surplus production: surplus production is growth plus recruitment minus mortality; if production would cause the stock biomass to increase it is "surplus" and can be taken as catch without decreasing the stock size; a concept central to the MSY paradigm.

sustainable yield: a catch that can be removed from a stock indefinitely without reducing the stock biomass; usually estimated with simplistic assumptions.

TAC/TACC: Total Allowable Catch and Total Allowable Commercial Catch limits set by the Minister for Primary Industries for a stock.

trace: refers to a plot of a parameter's values in the McMC simulation, plotted in the sequence they were obtained, taking every *n*th value of the simulation chain.

TW: tail width measured between the second abdominal spines.

vulnerability: outside the phrase vulnerable biomass (for which see below), means sex- and season-specific vulnerability; the relative chance of a lobster being caught, given its sex and the season; this allows males and females in the model to have different availabilities to fishing and for these to change with season.

vulnerable biomass: the biomass that is available to be caught legally: above the MLS, not egg-bearing if female, modified by selectivity and vulnerability; in the model this is called *Bvuln*; for comparing biomass with *Bref* and for reporting historical trajectories, the model calculates *Bvulref* using the last year's selectivity and MLS for consistency of comparison.

weights for datasets: weights are used to balance the importance of the different datasets to minimisation; higher weights decrease the sigma term in the likelihood and increase the contribution to the function value from that dataset; usually adjusted iteratively to achieve sdnr or MAR targets.

Z: total instantaneous mortality rate; $Z = F + M$.