The 2011 stock assessment and management procedure development for red rock lobsters (*Jasus edwardsii*) in CRA 4

Paul A. Breen[1]
Vivian Haist[2]
Paul J. Starr[3]
Marine Pomarede[4]

[1]12 Birkhall Grove
Wellington 6022

[2]1262 Marina Way
Nanoose Bay
British Columbia, Canada V9P 9C1

[3]61A Rhine Street
Wellington 6021

[4]NZ Seafood Industry Council
P.O. Box 24901
Wellington 6142

New Zealand Fisheries Assessment Report 2012/09
March 2012

Published by Ministry of Agriculture and Forestry
Wellington
2012

ISSN 1175-1584 (print)
ISSN 1179-5352 (online)
ISBN 978-0-478-38813-8 (online)

Breen, P.A.; Haist, V.; Starr, P.J.; Pomarede, M. (2012).
The 2011 stock assessment and management procedure development for red rock lobsters (*Jasus edwardsii*) in CRA 4.
New Zealand Fisheries Assessment Report 2012/09. 98 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry of Agriculture and Forestry
P O Box 2526
WELLINGTON

Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry of Fisheries website at
http://fs.fish.govt.nz go to Document library/Research reports
or the MAF website at:
http://www.maf.govt.nz/news-resources/publications.aspx

EXECUTIVE SUMMARY

Breen, P.A.; Haist, V.; Starr, P.J.; Pomarede, M. (2012). The 2011 stock assessment and management procedure development for red rock lobsters (*Jasus edwardsii*) in CRA 4.

***New Zealand Fisheries Assessment Report 2012/09*. 98 p.**

This document describes a stock assessment of red rock lobsters in CRA 4 and development of operational management procedures. The work was conducted by the 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, used as a single-stock model, with only minor changes made to the basic model. The Rock Lobster Fishery Assessment Working Group (RLFAWG) oversaw this work and all technical decisions were agreed beforehand or subsequently approved by that group.

The model was fitted to two abundance indices, size frequency data, tag-recapture data and, after a set of randomisation trials, a puerulus settlement index. This document describes the procedures used to find an acceptable base case and shows the model fits. Sensitivity trials are described. The assessment was based on Markov chain-Monte Carlo (McMC) simulations, and the document describes the diagnostics for these and shows the results of the McMC sensitivity trials. Short-term projections were made at the current assumed levels of catch and with an alternative catch level with a lower level of recreational catch.

The assessment showed that current vulnerable biomass is well above all reference levels. Although biomass is projected to decline slightly in the short term at current catch levels, it will remain well above reference levels.

The assessment model was used as the basis for an operating model to test management procedures based on a “plateau rule” form. Results comprised a set of agreed indicators obtained from runs with the base case and an agreed set of robustness trials. In all trials, the behaviour of the stock was satisfactory under all rules examined. Final management procedure candidates were presented to the National Rock Lobster Management Group.

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

1. INTRODUCTION

This document describes work conducted under Objective 4 of the Ministry of Fisheries[1] (MFish) contract CRA2009-01B. This contract, a three-year contract that began in April 2010, was awarded to the New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted Objectives 3 and 4 to the authors of this report. The authors collaborated on all aspects of Objective 4 to produce a jointly authored stock assessment.

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

Specific objectives confirmed by the National Rock Lobster Management Group (NRLMG) and MFish under Objective 4 were: 1) a stock assessment for red rock lobsters (*Jasus edwardsii*) in stock CRA 4, followed immediately by 2) a CRA 4 management procedure review.

This document describes the stock assessment and development of management procedures for red rock lobsters (*Jasus edwardsii*) in CRA 4. A companion document (Starr et al. 2012) describes the input data. A Glossary is provided to make the document accessible to non-technical readers.

The CRA 4 fishery extends from the Wairoa River on the east coast of the North Island, southwards along the Hawkes Bay, Wairarapa and Wellington coasts, through Cook Strait and north to the Manawatu River on the west coast.

2. Model

The 2011 stock assessment of CRA 4 used the multi-stock length-based model (MSLM) (Haist et al. 2009) as a single-stock model for the CRA 4 stock.

In MSLM, the population is represented as numbers of individuals kept separate by region or stock, sex, and size class. For this assessment, only one region was used, CRA 4. The model's time step is variable: for this assessment, the population was initialised in 1945 with an annual time step, changing to a semi-annual time step for the spring–summer (SS, October–March) and autumn–winter (AW) seasons for 1979 onwards.

Estimated model parameters can include: base recruitment and annual recruitment deviations for 1945–2011; natural mortality, growth parameters, selectivity parameters, sex- and season-specific vulnerability relative to a specified sex and season, maturation, catchability coefficients that relate to abundance and settlement indices, and parameters describing the shape of the relation between biomass and CPUE.

The initial population in 1945 was assumed to be in equilibrium, with average recruitment and no fishing mortality. For each subsequent time step, the numbers of male, immature female and mature female lobsters within each size class were updated as a result of:

Recruitment: each year, new recruits were added equally for each sex and both seasons as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). No stock-recruit relation was assumed. Recruitment in each year was determined by the parameter for base recruitment, *R0*, and the annual deviation from base

[1] now part of the Ministry of Agriculture and Forestry

recruitment, *Rdev*. The vector of recruitment deviations was assumed to be normally distributed with a mean of zero in log space.

Mortality: natural (*M*), fishing (*F*) and handling mortalities were applied to each sex category (male, immature female and mature female) in each size class. Natural mortality was estimated, but assumed to be constant and independent of sex category and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex- and season-specific vulnerabilities and selectivity curves.

Fisheries that respect size limits (SL fisheries) are differentiated from those that do not (NSL fisheries). Otherwise, selectivity and sex- and season-specific vulnerability functions were the same for these two fisheries. Mature females are not legally available in the AW season, when all are assumed to be ovigerous. Instantaneous fishing mortality rates *F* for each fishery were calculated simultaneously using a Newton-Raphson algorithm (four iterations were determined in experiments) based on catch and model biomass. Handling mortality rate was assumed to be proportional to legal fishing mortality at 10% of all lobsters released.

Fishery selectivity: a three-parameter selectivity function was assumed (double half-normal), with three parameters describing increasing selection from the initial size class to a maximum, followed by decreasing selection. Changes in regulation over time (for instance, changes in minimum legal size (MLS) and escape gap regulations) were modelled by estimating two sets of selectivity parameters: for years before 1993 and for 1993 and later years: the model calls these “epochs”. The model has an option for logistic selectivity that was not used except in initial experiments.

Growth and maturity: for each size class and sex category in a season, a transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. The growth model was a version of the Schnute (1981) continuous growth model. The model has an option for inverse logistic growth that was not used. Maturation for females was estimated as a two-parameter logistic curve.

Any parameter could be fixed at a specified value. Prior distributions and bounds were specified for all parameters, and the stock assessment was based on marginal posterior distributions, estimated with Markov chain—Monte Carlo (McMC) simulation. The model was implemented in AD Model Builder (http://admb-project.org/).

Abundance indices were fitted with lognormal likelihood, where the variance component for each datum was a function of the uncertainty estimate from standardisation (CPUE only), an assumed process error and the relative weight given to the dataset. Tag-recapture data were fitted with robust normal likelihood, where the variance component for each datum was a function of the standard deviation of the predicted increment (determined by the estimated CV of growth and the predicted increment, and limited by an assumed minimum standard deviation), an assumed observation error and the relative weight given to the dataset.

Length frequency (LF) data were fitted with multinomial likelihood. The multinomial sample size was determined by the weight given to each record (Starr et al. 2012) and the relative weight given to the dataset.

For this assessment, some further model options were:

- the model had 93 length bins, 31 for each sex group (males, immature and mature females), each 2 mm tail width (TW) wide, beginning at left-hand edge 30 mm TW;
- the initial base case was fitted to data for catch per unit of effort (CPUE), historical catch rate (CR), length frequencies (LFs) and tagging data; after preliminary trials the final base case was also fitted to a puerulus settlement index;

- fitting to LFs was restricted to the length bins for each sex that had appreciable numbers of observed fish; the fish in bins outside this range were added to the first or last bin, which was treated as a plus group or minus group; for the final base case we used the 3rd to 25th bins for males, the 4th to 19th for immature females and the 6th to 31st bins for mature females;
- fishing mortality rate *F* was determined with four Newton-Raphson iterations;
- sex- and season-specific vulnerability in the final base case was estimated relative to females in season SS with an upper bound of 1; relative sex- and season-specific vulnerability for immature females was the same as for mature females and different in the AW and SS seasons;
- the model assumed a linear relation between CPUE and abundance;
- minimum standard deviation (s.d.) of growth was fixed at 0.9 mm (based on exploratory fits) and observation error s.d. at 1.0 mm;
- two selectivity epochs were assumed: 1945–92 and 1993–2009;
- process error for CPUE was assumed to be 0.25;
- process error for CR was assumed to be 0.30;
- density-dependent growth was not used;
- the MSLM movement option was not used.

Puerulus data were fitted by predicting puerulus from recruitment, with an estimated scalar and an appropriate lag, using lognormal likelihood. *Bmsy* was calculated by making a series of forward projections for 50 years, using deterministic recruitment at *R0* and using a multiplier on the estimated current *F* values for the size-limited (SL) fishery in the AW and SS seasons, while NSL catch remained at its 2010 value.

Estimated *Bmsy* is the biomass (the beginning of season AW vulnerable biomass) associated with the maximum yield *MSY* (annual SL catch), and the multiplier *Fmult* is the multiplier that produces *MSY*. Other indicators and the snail trail will be described below.

This is a general overview of the model: further details are provided by Haist et al. (2009).

3. Finding a base case

3.1 Overview

Immature females were not well represented in the CRA 4 catch sampling data, representing fewer than 2% of all fish sampled (Figure 1). Mature females were better represented, accounting for 42% of all fish measured; the rest were males.

Two alternative hypotheses might explain the low proportion of immature females in the catch samples:

1) immature females are relatively invulnerable to the fishing gear;
2) most females mature at a relatively small size (below 45 mm TW).

When seasonal vulnerability was estimated separately for mature and immature females, the model fits supported hypothesis 1); when seasonal vulnerability was linked between immature and female females, the model fits supported hypothesis 2). Neither hypothesis is completely satisfactory, so two alternative initial base cases were presented to the RLFAWG.

These initial base cases were not fitted to the puerulus data. Following the practice for the 2010 stock assessment for CRA 5 (Haist et al. 2011), after choosing an acceptable initial base case we conducted a set of puerulus randomisation trials to determine whether the puerulus settlement data contained a significant signal. As discussed below, these trials indicated a strongly significant signal, so the final base case was fitted to the puerulus data. Some material is presented from the initial base cases, but most material presented here relates to the final base case.

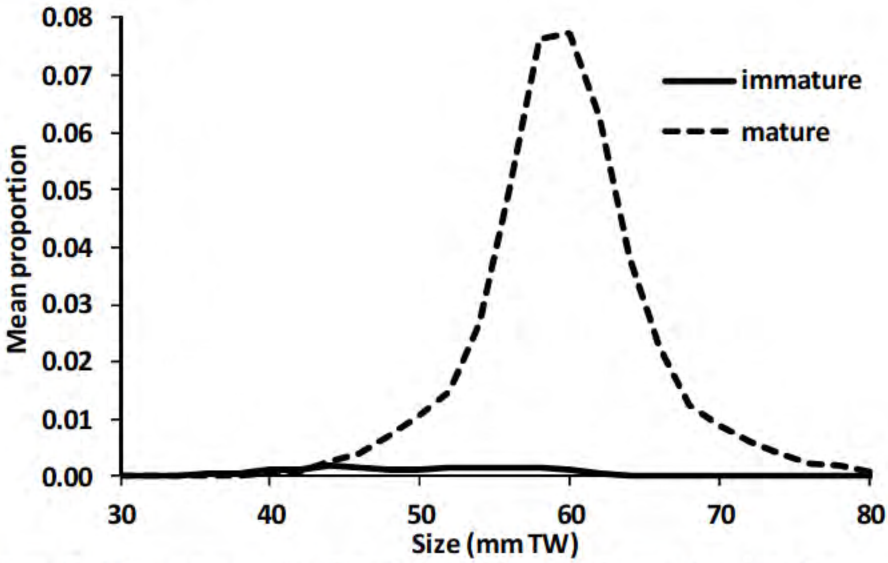

Figure 1: The average proportion-at-length for immature and mature females across all CRA 4 length frequency samples (including both logbook and observer catch sampling).

3.2 Initial base case

In the process of searching for an initial base case, we made approximately 150 runs, experimenting with:

- relative weights for each dataset;
- weighting the LFs with the method suggested by Francis (2011);
- whether the growth CVs were fixed or estimated;
- whether the growth shape was fixed or estimated;
- the pattern of vulnerability by sex and season, as explained below;
- whether maturity parameters were fixed or estimated;
- whether model options such as density-dependence made a substantial improvement.

The Francis (2011) LF weighting involved predicting the mean length of each LF record and comparing it with the observed mean length. This was not a part of the fitting, but the standard deviation of residuals and median absolute normalised residual were calculated, and iterative re-weighting was based on these instead of the residuals from the actual LF fitting. This alternative method led to much lower weights for the LF data.

Problems with these explorations involved:

- estimated growth shape parameter being too high, leading to extreme curvature of the relation between increment and initial size and allowing unrealistically high growth of sub-legals;
- high M in most runs, especially with relatively low weight on LFs;
- high parameter values for the estimated size at 50% maturation or the difference between 50% and 95% sizes
- very low vulnerability for immature females;
- poorly formed Hessian matrices, preventing us from proceeding to McMC.

The model estimates four sex-seasonal vulnerability parameters (*vuln1* through *vuln4*) relative to a specified sex and season that has relative vulnerability of 1. The specified sex-season with vulnerability 1 has, in all past assessments, been males in season AW or SS, while immature and mature females have been given the same vulnerability in SS. For this assessment, it appeared from experimental fits that mature females in SS had the highest vulnerability. For initial base case *base1*, immature females were assumed to have different vulnerability from mature females but the same vulnerability in each season. In initial base case *base2*, immature and mature females were assumed to have the same vulnerability as each other, and vulnerability differed between seasons. For both initial base cases, mature females in SS were assumed to have the highest vulnerability. For *base1* this was specified in the usual way; in *base2* one of the normally estimated vulnerability parameters, *vuln4*, was fixed to 1.0 (Table 1).

Table 1: Showing which estimated relative vulnerability parameter was applied to which sex-season combination; "n.a." indicates that relative vulnerability was set to 1; asterisks indicate a parameter fixed to 1.

	base1		*base2*	
Sex	AW	SS	AW	SS
Male	*vuln1*	*vuln2*	*vuln1*	*vuln2*
immature female	*vuln3*	*vuln3*	*vuln3*	**vuln4*
mature female	*vuln4*	*n.a.*	*vuln3*	**vuln4*

After several days of experimentation, for both *base1* and *base 2* the following choices were made:

- Francis (2011) weighting for LFs
- other data sets weighted to obtain MAR close to 0.67 (with less emphasis on the CR data);
- growth CV estimated;
- a strong arbitrary prior (the same as used in CRA 5) on growth shape to prevent very high shapes (there is little information in the data);
- a pragmatic prior on the maturation parameter *mat95add* to keep the maturation ogive narrow;
- *Rdev*s estimated from 1945–2007;
- double-normal selectivity with the parameter for the right-hand limb fixed at 200 as in previous assessments.

There was a tendency for higher LF weight to give lower *M* in the MPDs, but trial McMCs suggested that *M* could climb from the MPD value during the run. High LF weights led to other problems in the McMC. In extensive trials, we could not find any solution to the high estimated *M* and we decided to accept it.

For estimated parameters, Table 2 shows the phases, bounds and priors used for the two initial base cases and shows the MPD estimates. The weights for datasets, resulting likelihoods and their diagnostics, and some derived parameters estimates are shown in Table 3. The two initial base cases showed quite similar parameter estimates apart from the relevant relative vulnerabilities and for the maturation parameters.

Table 2: For estimable parameters, base case values for the estimation phase, lower and upper bounds, prior, initial values and estimated values from the two base cases. A negative phase indicates a fixed parameter. Prior types 0: uniform, 1: normal and 2: lognormal. Parentheses for the selectivity parameters show the epoch.

Description	Parameter	Phase	lb	ub	Prior type	Prior mean	Prior std.dev.	Init value	*Base1* est	*Base2* est
Base recruitment	*ln(R0)*	1	1	25	0	0	0	14	15.19	15.18
Natural mortality	*M*	5	0.01	0.35	2	0.12	0.4	0.12	0.291	0.301
Recruitment deviations	*Rdevs*	3	-2.3	2.3	1	0	0.4			
Catchability	*ln(qCPUE)*	1	-25	0	0	0	0	-6	-6.539	-6.582
Catchability	*ln(qCR)*	1	-25	2	0	0	0	-3	-2.650	-2.475
Catchability	*ln(qpuerulus)*	-1	-25	0	0	0	0	-6	n.a.	n.a.
Shape of CPUE	*CPUEpow:*	-1	0.001	2	0	0	0	1	n.a.	n.a.
TW at 50%maturation	*Mat_50*	4	30	80	0	50	10	50	62.73	38.54
For TW at 95% maturation	*Mat_95Add*	4	5	80	1	14	2.8	14	13.98	13.84
Male growth at 50 mm TW	*Galpha_M*	2	0.1	20	0	0	0	3.2	3.23	3.28
	Galpha_F	2	0.1	20	0	0	0	3.2	3.04	3.10
For TW at 80 mm	*Gdiff_M*	2	0.001	1	0	0	0	0.6	0.619	0.590
	Gdiff_F	2	0.001	1	0	0	0	0.6	0.398	0.399
Male growth at 80 mm TW	*GBeta_M*								2.00	1.93
	GBeta_F								1.21	1.24
Shape of growth	*Gshape_M*	3	0.1	15	1	5	0.5	5	5.608	5.748
	Gshape_F	3	0.1	15	1	5	0.5	5	5.657	5.772
Growth CV	*GrowthCV_M*	4	0.01	5	0	0	0	0.5	0.400	0.397
	GrowthCV_F	4	0.01	5	0	0	0	0.5	0.633	0.645
Min s.d. of growth increment	*minStdDev*	-2	0.01	5	0	0	0	0.9	0.9	0.9
Observation error	*ObsSdDev*	-1	0.00001	10	0	0	0	1	1.0	1.0
Selectivity shape, left, male, epoch 1	*SelVL_M(1)*	4	1	50	0	0	0	4	7.15	7.68
	SelVL_F(1)	4	1	50	0	0	0	7	7.69	16.14
	SelVL_M(2)	4	1	50	0	0	0	4	5.15	5.16
	SelVL_F(2)	4	1	50	0	0	0	7	12.37	8.07
Selectivity shape, right, male, epoch 1	*SelVR_M(1)*	-3	1	250	0	0	0	200	200	200
	SelVR_F(1)	-3	1	250	0	0	0	200	200	200
	SelVR_M(2)	-3	1	250	0	0	0	200	200	200
	SelVR_F(2)	-3	1	250	0	0	0	200	200	200
Maximum selectivity	*SelMax_M(1)*	4	30	80	0	54	2	54	57.16	58.09
	SelMax_F(1)	4	30	80	0	60	2	60	49.02	80.00
	SelMax_M(2)	4	30	80	0	54	2	54	56.38	56.22
	SelMax_F(2)	4	30	80	0	60	2	60	66.67	68.36
Vulnerability	*vuln1*	3	0.01	1	0	0	0	0.8	0.770	0.783
	vuln2	3	0.01	1	0	0	0	0.8	0.564	0.558
	vuln3	3	0.01	1	0	0	0	0.8	0.014	0.760
	vuln4(Base1)	3	0.01	1	0	0	0	0.8	0.731	
	vuln4(Base2)	-3	0.01	1	0	0	0	1		1.000

Table 3: Weights and resulting standard deviations of normalised residuals (sdnr), median of absolute residuals (MAR) and likelihood contribution (LL) for each data set in the initial base case; contributions from priors and the total function value, and some population indicators from the base case MPD fit.

	Base1				*Base2*			
Item	Weight	sdnr	MAR	LL	Weight	sdnr	MAR	LL
LFs	3.5	1.033	0.129	155.50	3.5	1.093	0.138	168.71
Tags	0.8	1.260	0.668	3550.91	0.8	1.255	0.668	3551.09
CPUE	3	1.260	0.692	-79.67	4	1.205	0.701	-82.07
CR	3	0.766	0.535	34.79	4	0.720	0.536	31.24
Rdev prior				-40.13				-38.28
M prior				1.69				1.92
Growth_priors				0.22				0.92
Other priors				-0.55				-0.55
Total function value				3622.74				3632.98
Depletion	1.909				1.809			
Bref	428.5				474.2			
Bmsy	404.7				396.9			
MSY	645.1				655.3			
Fmult	3.34				3.67			

The differences between the two initial base cases are shown in Figure 2 through Figure 5. The first two figures show the maturation curves: *base1* showed late maturation and *base2* showed early maturation. Combined with the very low vulnerability of immature females in *base1* (Table 2), this is how the two initial base cases explained the very low proportions of immature females in the LF data (Figure 1).

These differences result in quite different initial length structures (Figure 4 and Figure 5), especially with respect to mature females.

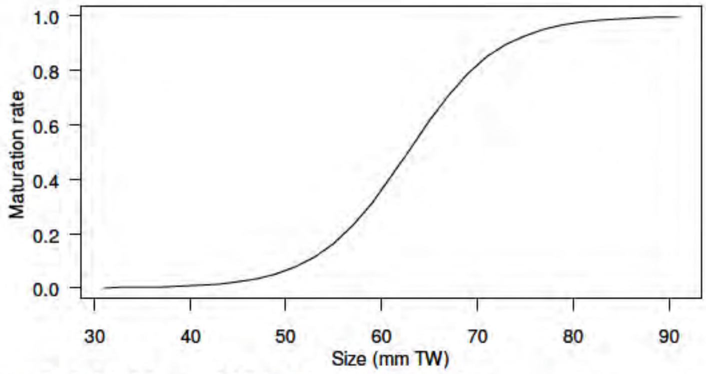

Figure 2: Initial *base1* MPD: Maturation ogive.

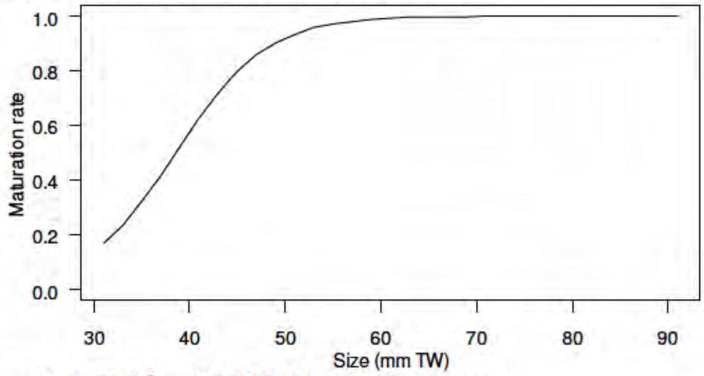

Figure 3: Initial *base2* MPD: Maturation ogive.

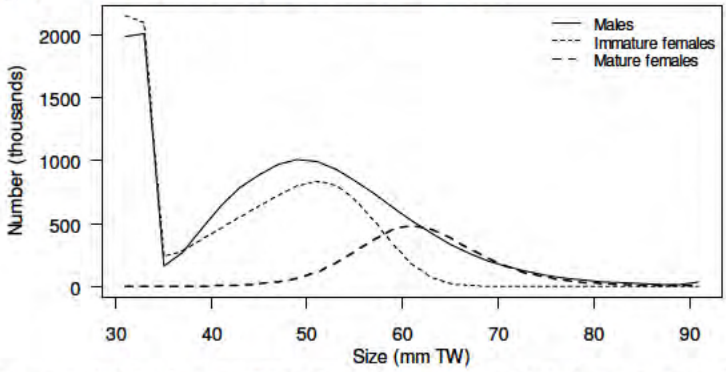

Figure 4: Initial *base1* MPD: The model's unfished size structure by sex category.

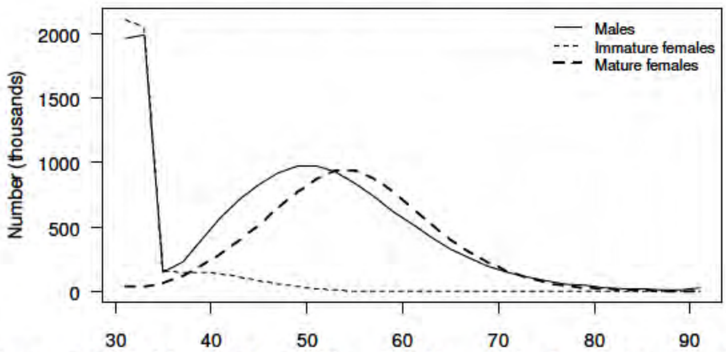

Figure 5: Initial base2 MPD: The model's unfished size structure by sex category.

A variety of diagnostic plots were shown to the RLFAWG. The WG agreed that only a single base case should be pursued, and that this should be initial base 2, with immature female vulnerability made the same as for males.

3.3 Puerulus randomisation trials

Trials to determine whether there was a signal in the puerulus data were made by fitting the model to the puerulus settlement data with a specified lag from 0 to 5 years between settlement and recruitment to the model, which occurred with mean 32 mm TW. At each specified lag, 500 additional fits were made with a randomised puerulus settlement vector obtained by resampling the data. Under the null hypothesis – that there is no signal in the data – the function value from the fit to real data should fall in the centre of the distribution of function values from the resampled data. A significant result is found when the function value is in the lower 5% of the distribution (this is a one-tailed test).

Results from the trials using what became the final base case (Table 4) showed that all lags from 0 through 3 years were significant, with 1 year giving the best result. A lag of zero is biologically unrealistic, but the model's growth between 32 mm and MLS may be under-estimated, so in practice such a lag might be realistic. The model has no data from which to estimate growth near 32 mm TW, and few data until sizes are near the MLS.

In experimental fits, the puerulus had a strong effect on the model's estimated recruitment pattern (Figure 6). There was a correlation between the puerulus index and the model's recruitment even when the settlement index was not fitted (r = 0.53); estimated recruitment became similar to the puerulus settlement index when the model used the settlement index. Figure 7 shows the effects of lag on the model's recruitment estimates.

Table 4: P-values for puerulus randomization trials run for lags of 0 to 5 years for the final base case.

Lag	P
0	0.006
1	0.000
2	0.002
3	0.020
4	0.056
5	0.342

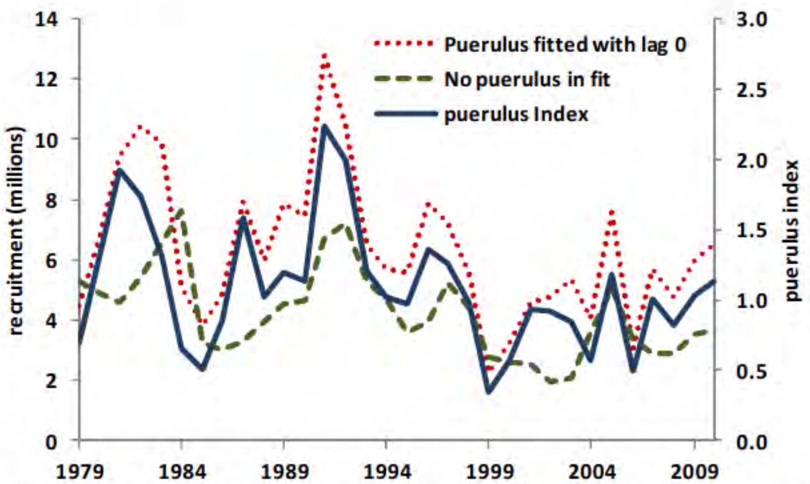

Figure 6: The MPD *base1* recruitment trajectory when not fitted to puerulus and when fitted to the settlement index with a lag of zero, compared with the settlement index.

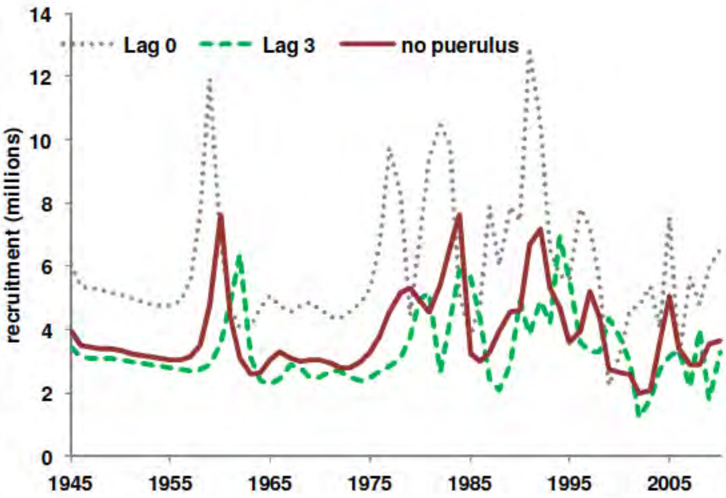

Figure 7: The MPD *base1* recruitment trajectory when not fitted and when fitted to the settlement index with lags of 0 or 3 years.

3.4 Final base case

The final base case was based on initial base case *base2*, which explained the dearth of immature females in the LF data on the basis of early maturation. This final base case was fitting to puerulus settlement with a 1-yr lag (see Table 4). Two other changes were necessary between *base2* and the final base case. First, to use all the puerulus data with an assumed lag of 1 year between settlement and recruitment, ***Rdevs*** through 2011 were estimated, whereas in *base2* the last estimated ***Rdev*** was 2007. Second, the dataset weight for LFs was reduced from 3.5 to 3.15, a change necessary to obtain pdH.

Parameter values from *base2* and the final base case are compared in Table 5. Differences caused by the changes were minor.

Table 5: Estimated MPD and derived parameters from the final base case (right column), compared with the initial base case *base2*.

Value	*Base2*	Final base
LFs-Lswitch	1	1
LFs-weight	3.50	3.15
LFs-sdnr	1.093	1.084
LFs-MAR	0.138	0.133
LFs-LL	168.7	156.8
Tags-Lswitch	1	1
Tags-weight	0.80	0.80
Tags-sdnr	1.255	1.251
Tags-MAR	0.668	0.666
Tags-LL	3551.1	3552.1
CPUE-Lswitch	1	1
CPUE-weight	4.00	4.00
CPUE-sdnr	1.205	1.379
CPUE-MAR	0.701	0.995
CPUE-LL	-82.1	-67.7
CR-Lswitch	1	1
CR-weight	4.00	4.00

Value	*Base2*	Final base
CR-sdnr	0.720	0.723
CR-MAR	0.536	0.655
CR-LL	31.2	31.3
Poo-Lswitch	0	1
Poo-weight	n.a.	1.00
Poo-sdnr	n.a.	1.032
Poo-MAR	n.a.	0.532
Poo-LL	n.a.	-20.1
Priors	-36.0	-38.8
Function value	3633.0	3613.6
ln(*R0*)	15.183	15.436
M	0.301	0.326
ln(*qCPUE*)	-6.582	-6.575
ln(*qCR*)	-2.475	-2.439
ln(*qpuerulus*)	n.a.	-15.394
mat50	38.54	39.169
mat95add	13.84	13.93
Galpha_M	3.28	3.14
GBeta_M	1.93	2.05
Gdiff_M	0.59	0.65
Gshape_M	5.75	5.37
GrowthCV_M	0.397	0.416
Galpha_F	3.10	3.08
GBeta_F	1.24	1.22
Gdiff_F	0.40	0.40
Gshape_F	5.77	5.63
GrowthCV_F	0.645	0.629
vuln1	0.783	0.733
vuln2	0.558	0.513
vuln3	0.760	0.755
VL1_M	7.676	7.067
SelectMax1_M	58.1	57.8
VL1_F	16.1	15.6
SelectMax1_F	80.0	80.0
VL2_M	5.2	5.1
SelectMax2_M	56.2	56.5
VL2_F	8.1	8.0
SelectMax2_F	68.4	68.8
Bcurr/Bref	1.81	1.72
Bref	474.2	464.2
Bmsy	396.9	358.8
MSY	655.3	674.0
Fmult	3.67	3.94
Yrs 32 to MLS_M	4.00	4.50
Yrs 32 to MLS_F	6.00	6.50

The final base case showed a good fit to CPUE (Figure 8) and good residual patterns (see Figure 9, Figure 10). The fit to CR (Figure 11) was also good. Fits to length frequencies are shown in Figure 12 and residuals are explored in Figure 13 through Figure 14. Francis (2011) suggests, when using his data weighting recommendations, comparing the predicted mean length (or age) in each data set as a diagnostic to see if the method is working. We used multinomial likelihood for this comparison. Figure 15 shows that the increasing trend in observed mean lengths has been captured by the model, as well as following a decline and recovery in the most recent 3–4 years. Predicted tag-recapture increments are compared with observed increments in Figure 16; QQ plots of the residuals are shown in Figure 17. Predicted increments-at-length are shown in Figure 18.

Figure 19 shows the maturation schedules and the resulting unfished size structure is shown in Figure 20. Selectivity curves are shown in Figure 21.

Trajectories are shown for recruitment (Figure 22), biomass (Figure 23) and exploitation rates (Figure 24). Surplus production is plotted against biomass in Figure 25. This plot suggests that the early fishery reduced biomass quickly, and that the stock has cycled through 20–40% of its original biomass with productivity cycling through a factor of three in that biomass range.

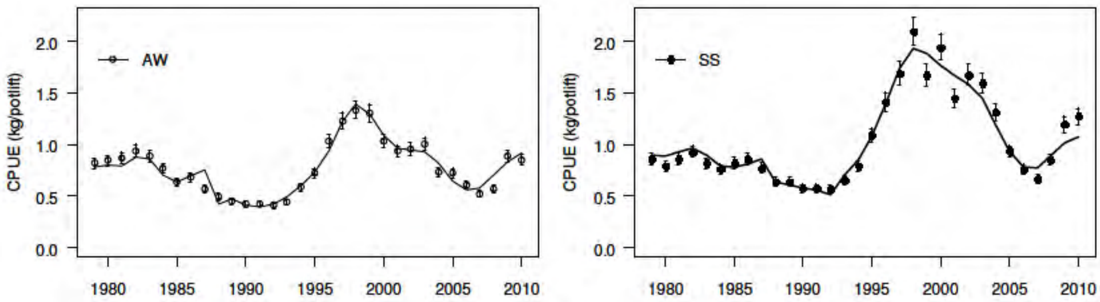

Figure 8: Final base case MPD: Observed CPUE (symbols) with their error bars and predicted (lines) CPUE in AW (upper) and SS seasons, plotted by fishing year.

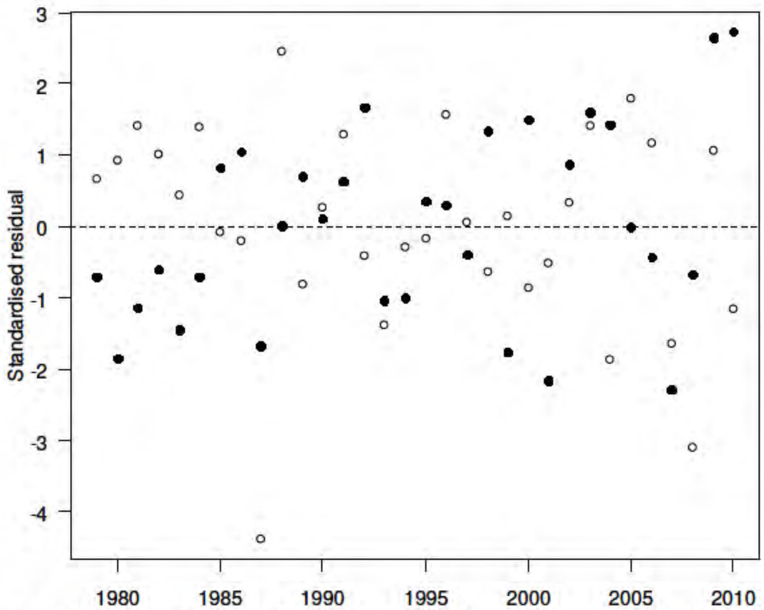

Figure 9: Final base case MPD: Normalised residuals from the fit to CPUE: open circles are AW, closed circles SS.

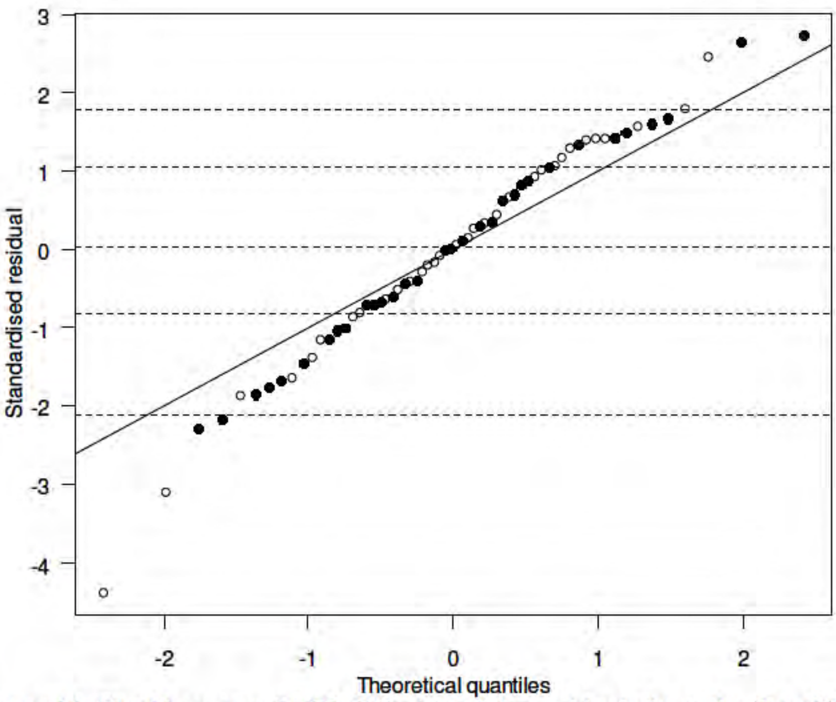

Figure 10: Final base case MPD: QQ plots of the residuals from the fit to CPUE: open circles are AW, closed circles SS.

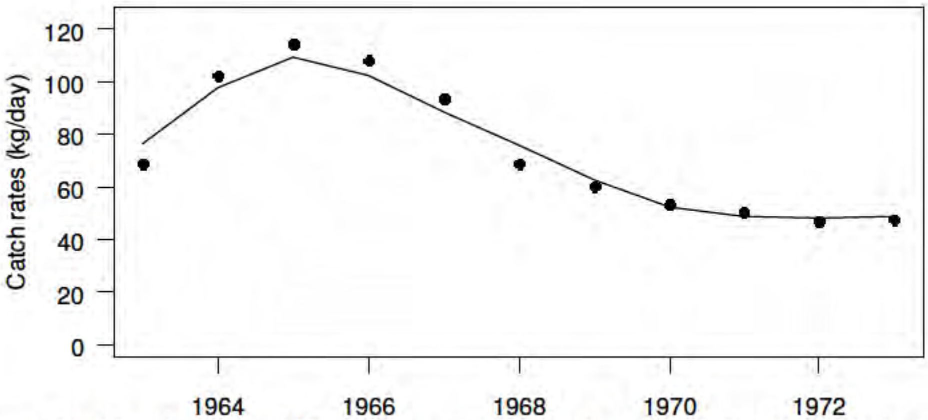

Figure 11: Final base case MPD: Observed (dots) and predicted (line) historical catch rate (CR) plotted by fishing year.

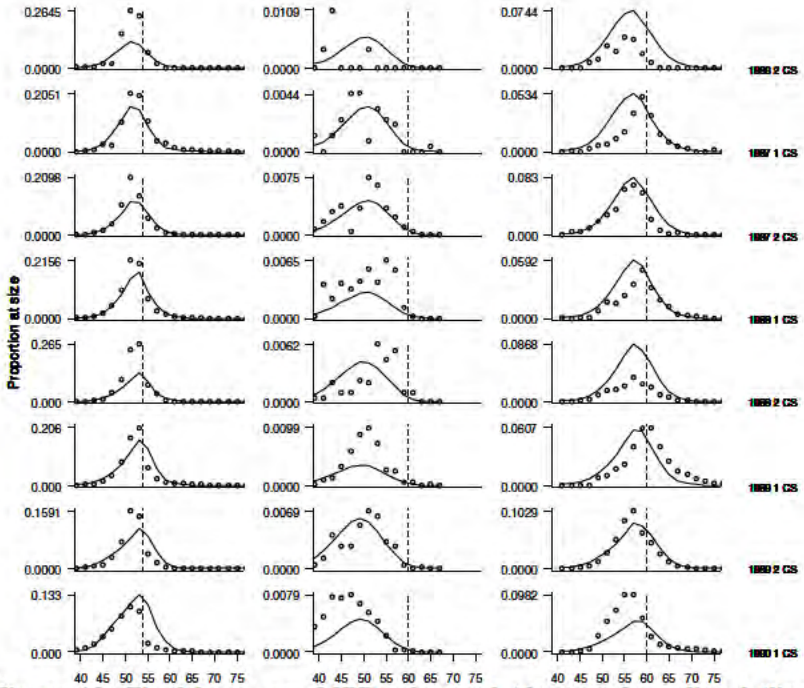

Figure 12: Final base case MPD: observed (dots) and predicted (lines) length frequencies for males (left), immature females (centre) and mature females. Data at the right of each set of plots gives the date, season (1=AW, 2=SS), source (LB=logbook, CS=observer catch sampling) and relative weight. Note that the y-axis scales for proportion-at-length change among plots.

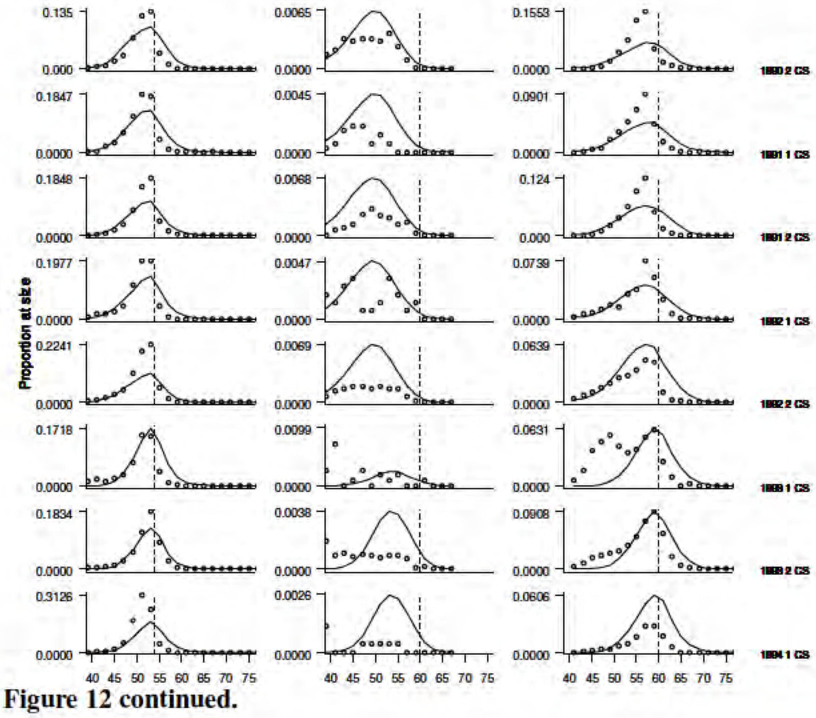

Figure 12 continued.

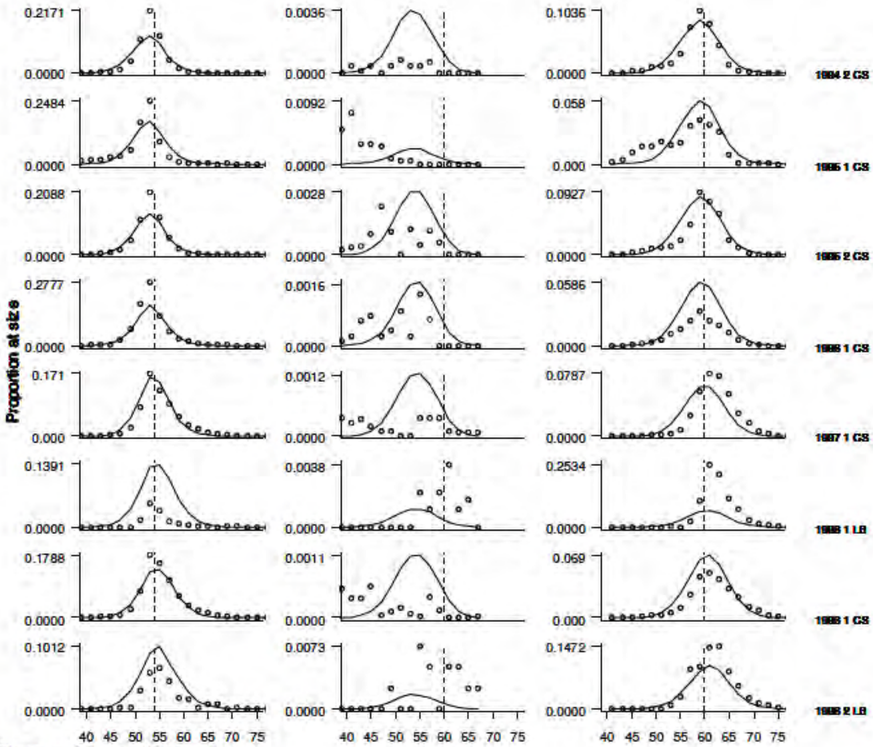

Figure 12 continued.

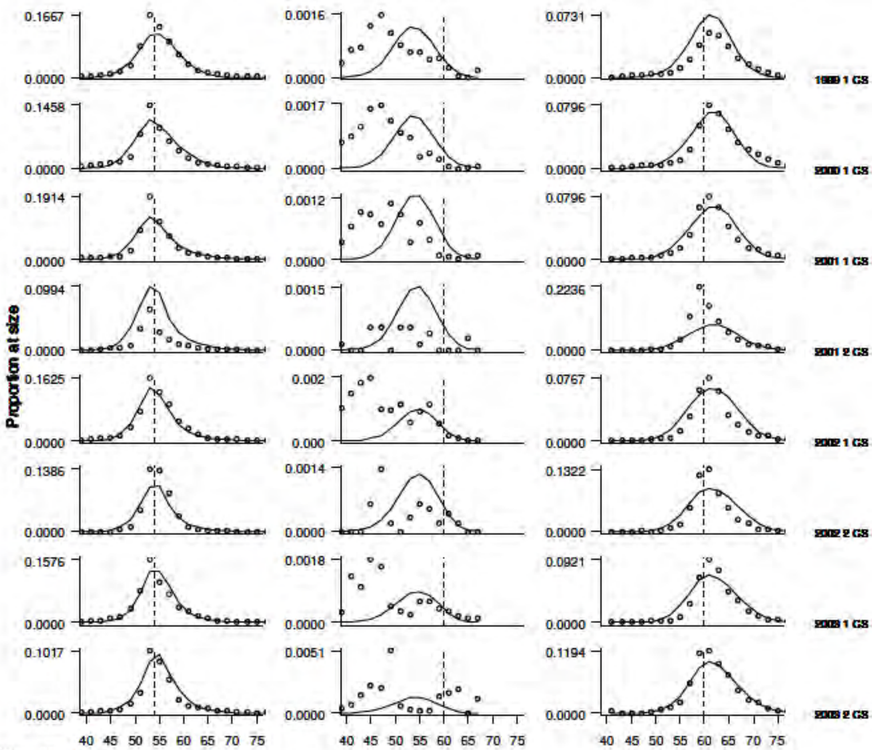

Figure 12 continued.

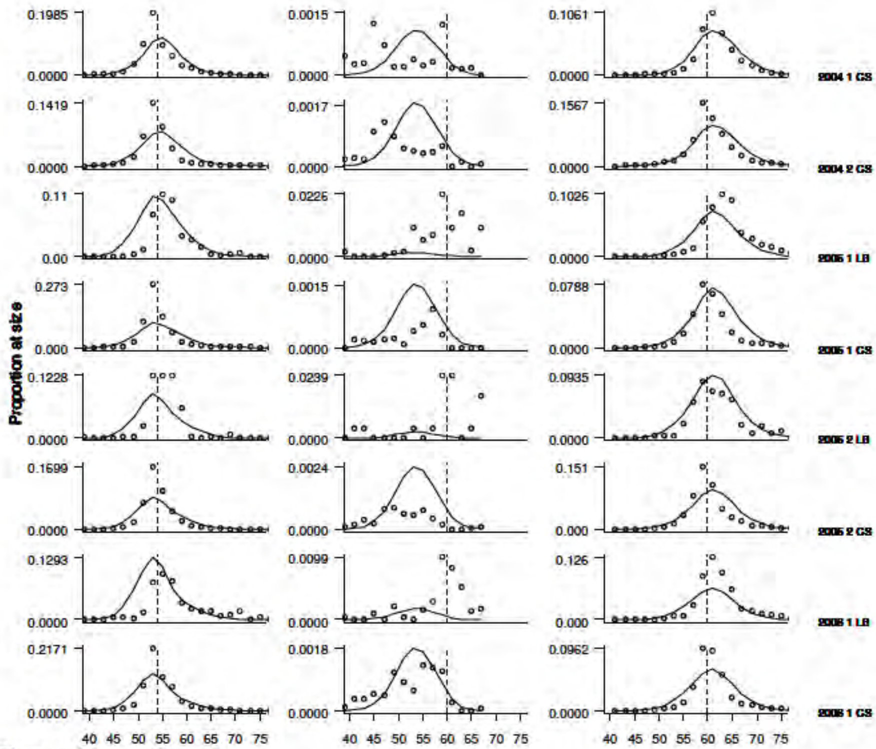

Figure 12 continued.

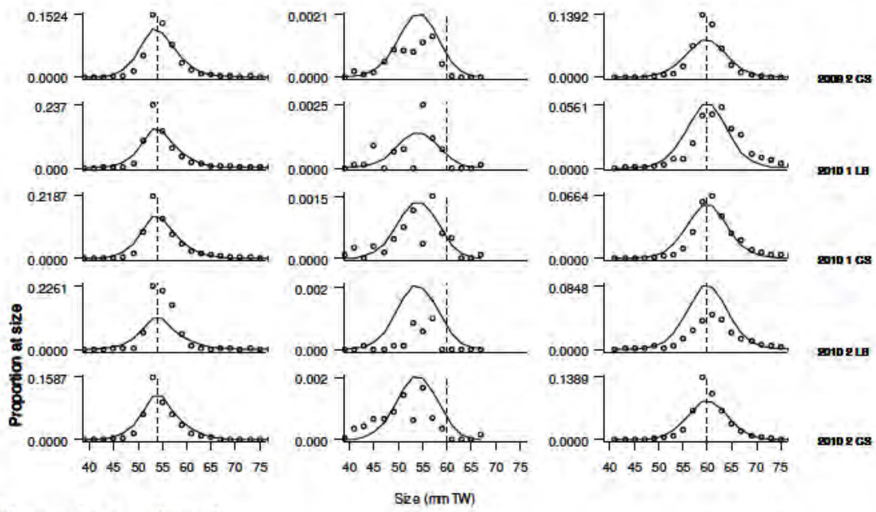

Figure 12 continued.

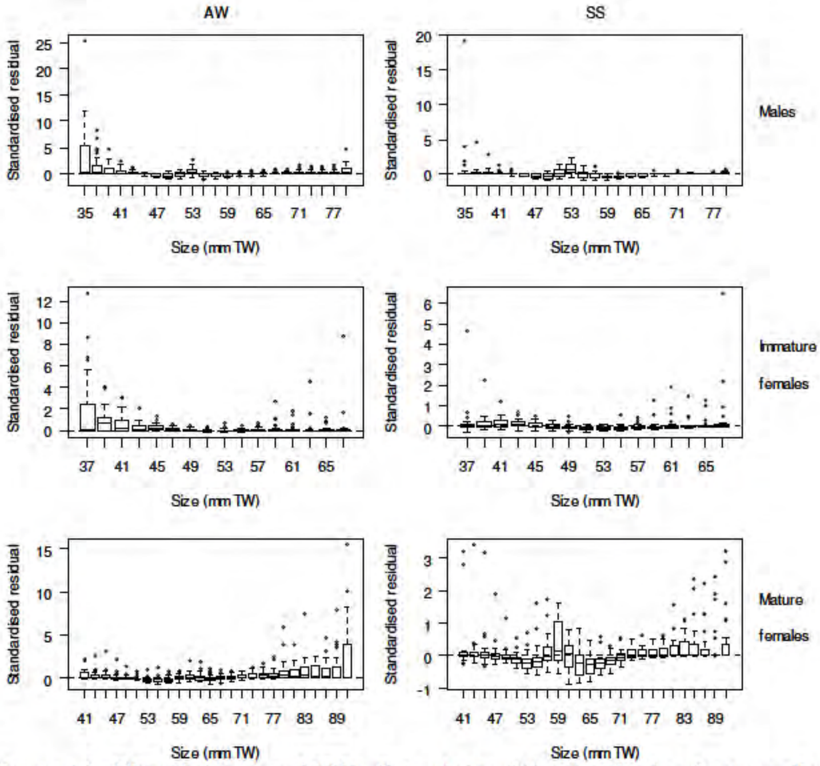

Figure 13: Final base case MPD: Box plots of the residuals of proportions-at-length by size, sex and season.

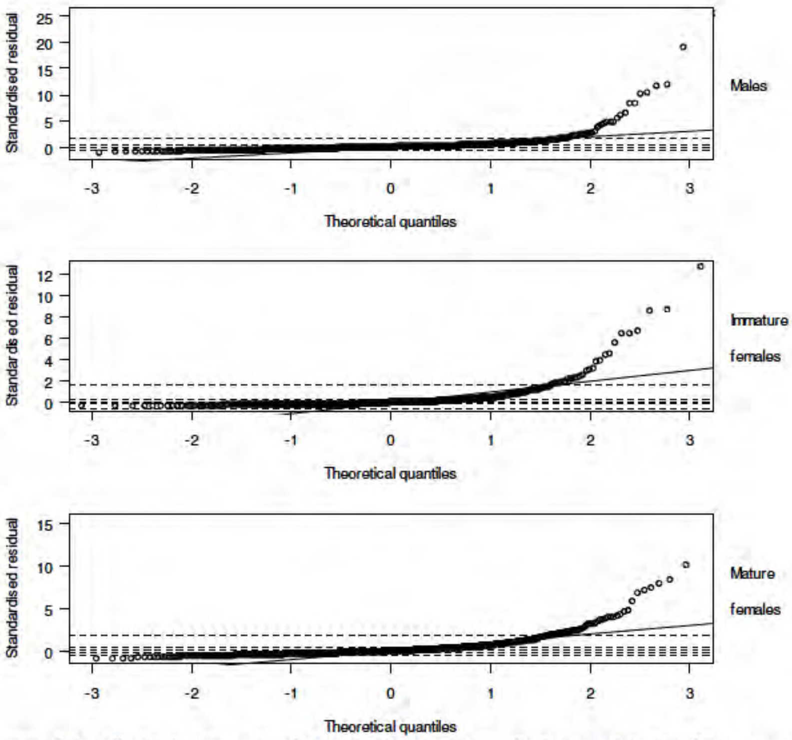

Figure 14: Final base case MPD: QQ plots of the residuals for proportions-at-length by sex. Horizontal lines are 5, 25, 50, 75 and 95 percent of normalised residuals.

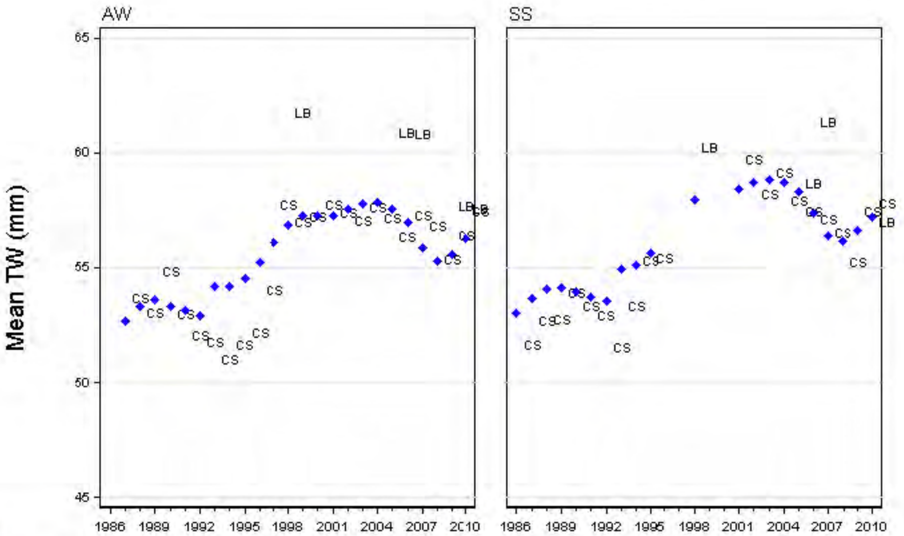

Figure 15: Final base case MPD: Observed (plotting symbol: LB=logbook and CS=catch sampling) and predicted (plotting symbol: diamond) mean lengths for each length frequency record as a function of year and season.

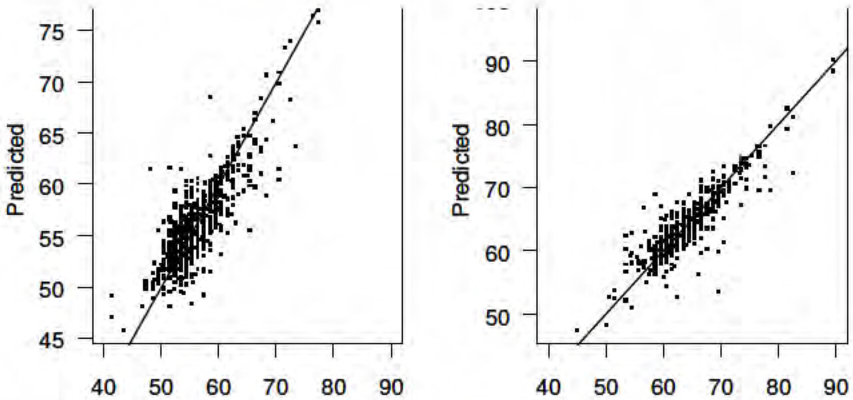

Figure 16: Base1 MPD: Predicted vs. observed increments in the tag-recapture data, plotted by sex against TW at release.

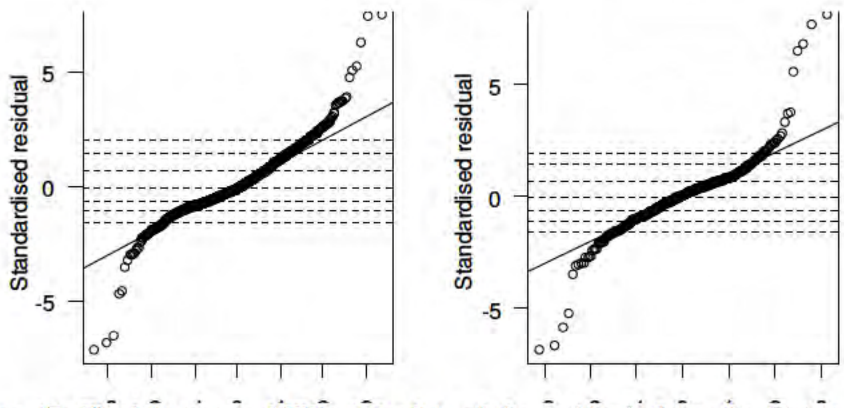

Figure 17: Final base case MPD: QQ plots of the residuals from the fit to tag-recapture data, plotted by sex.

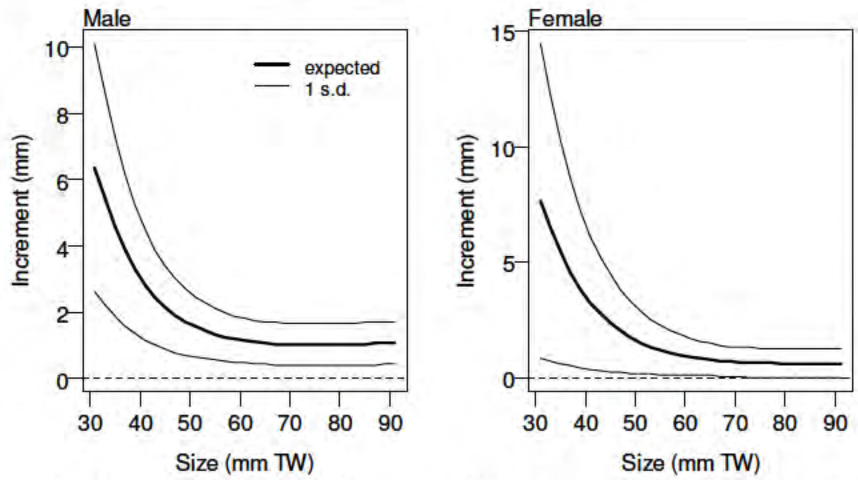

Figure 18: Final base case MPD: predicted increments-at-length for each sex and their 90% intervals.

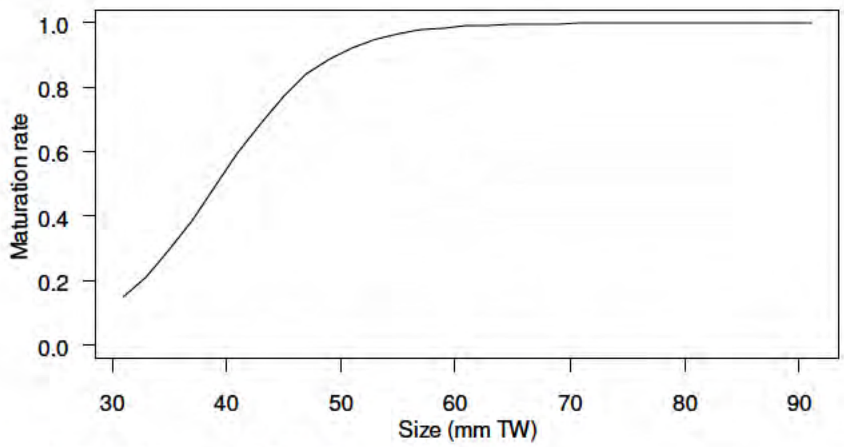

Figure 19: Final base case MPD: Maturation ogive.

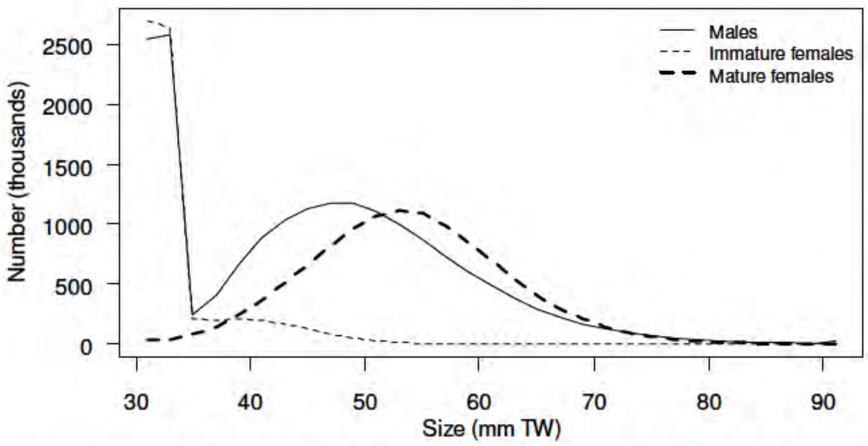

Figure 20: Final base case MPD: The model's unfished size structure by sex category.

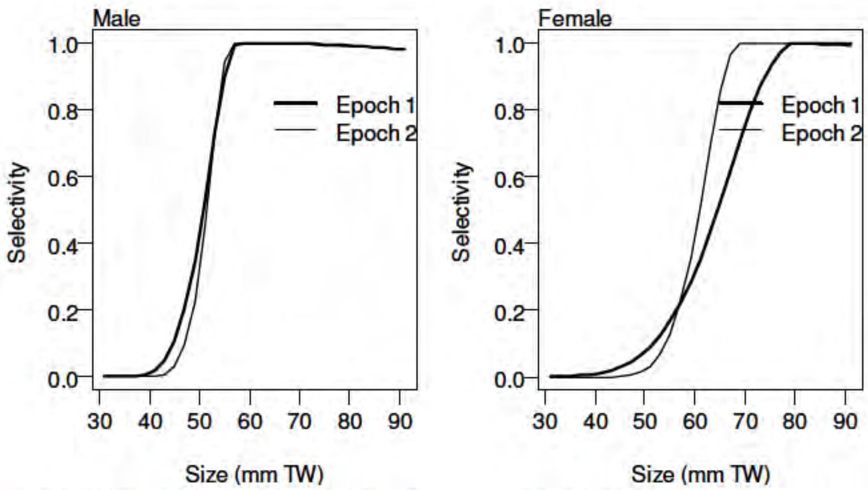

Figure 21: Final base case MPD: Selectivity by sex and epoch.

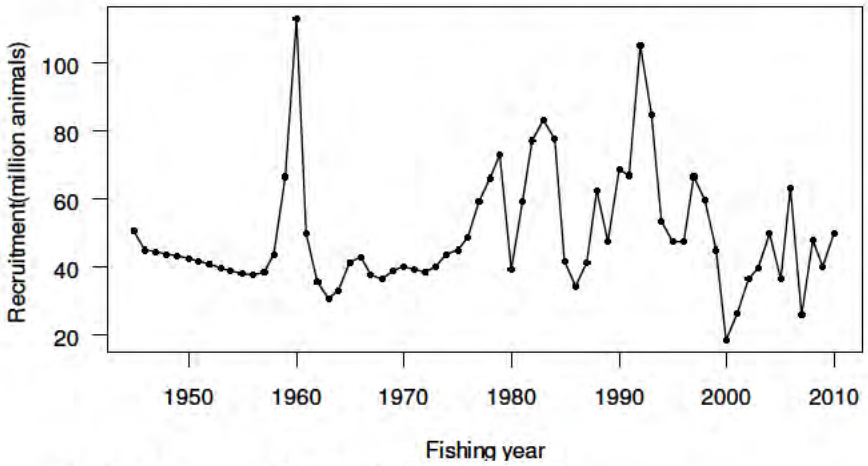

Figure 22: Final base case MPD: Recruitment trajectory.

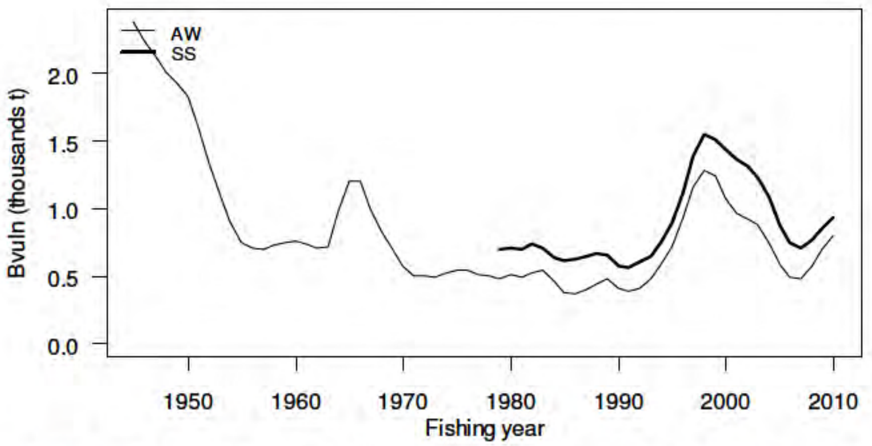

Figure 23: Final base case MPD: Vulnerable biomass trajectory. There are no SS points before 1979 because the time step was one year.

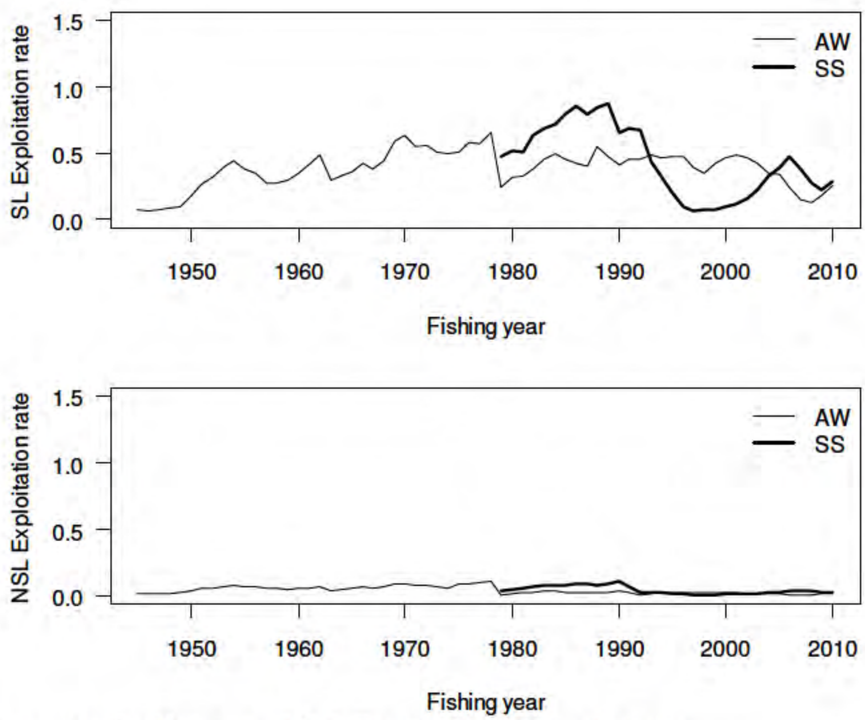

Figure 24: Final base case MPD: Exploitation rate trajectories.

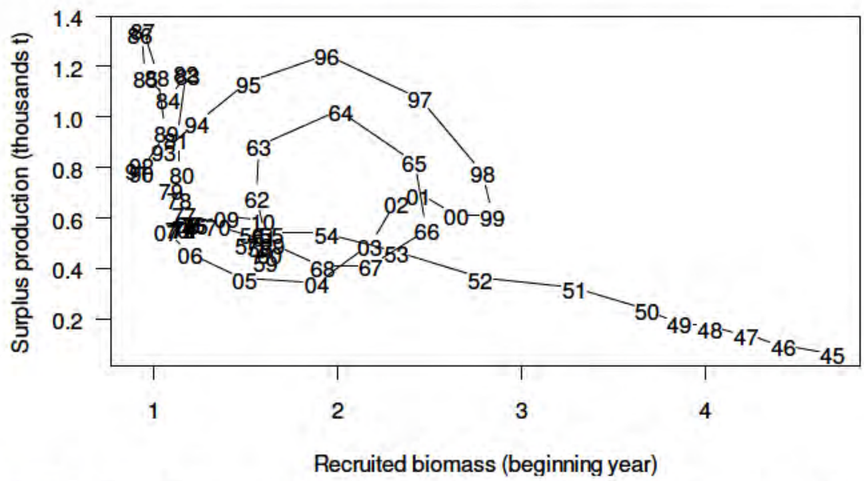

Figure 25: Final base case MPD: surplus production vs. biomass (biomass is scaled to *Bref*).

3.5 MPD sensitivity trials

The RLFAWG requested two sensitivity trials involving the LFs: one with no voluntary logbook records (there were only 1–3 participants until 2010, and the base case datafile included only some of these (Starr et al. 2012)) and one with no truncation of the calculated dataset weights at 1 and 10. We conducted other MPD sensitivity trials– the full list is:

1) no logbook data in the LF data;
2) no truncation of the LF record weights;
3) LF dataset weight increased from the Francis (2011) weight (near 3.5) to 20;
4) *M* fixed to 0.16 (near the values obtained with high LF weights);
5) the parameter estimated for the right-hand side of the selectivity curve (giving domed selectivity) (in the base case fixed at 200);
6) no LF data;

7) no tag-recapture data;
8) no CPUE data;
9) no CR data;
10) fitting to puerulus with weight 1.0;
11) estimating the relation between CPUE and abundance (linear in the base case).

We conducted these trials before we had made the final base case, using *base1* and *base2* (Table 6 and Table 7). For both base cases the trials with the biggest effects were the high LF weight and the fixed ***M***: these affected the growth parameters and the derived parameters. Growth parameters were also changed when no LFs were used or when no tags were used. The two trials requested by the WG had almost no effect on the results.

Table 6: MPD sensitivity trials (see list above) based on initial base case *base1*. Grey indicates items where a dataset was not used or a parameter was fixed at the value shown; an asterisk indicates that it was fixed.

		No	No				No	No	No	No		
		logs	trunc	LF20	M0.16	domed	LFs	tags	CPUE	CR	poo	pow
	base1	sens1	sens2	sens3	sens4	sens5	sens6	sens7	sens8	sens9	sens10	sens11
LFs-Lswitch	1	1	1	1	1	1	0	1	1	1	1	1
LFs-weight	3.50	3.50	3.50	20.00	3.50	3.50	n.a	3.50	3.50	3.50	3.50	3.50
LFs-sdnr	1.033	1.033	1.060	2.085	0.784	0.959	n.a	1.052	1.111	1.016	1.011	1.084
LFs-MAR	0.129	0.121	0.122	0.276	0.127	0.126	n.a	0.115	0.122	0.128	0.127	0.128
LFs-LL	155.5	123.6	156.6	773.0	152.6	154.3	n.a	145.0	142.8	155.6	159.6	152.9
Tags-Lswitch	1	1	1	1	1	1	1	0	1	1	1	1
Tags-weight	0.80	0.8	0.8	0.8	0.8	0.8	0.8	n.a	0.8	0.8	0.8	0.8
Tags-sdnr	1.260	1.260	1.259	1.271	1.268	1.266	1.271	n.a	1.265	1.258	1.253	1.260
Tags-MAR	0.668	0.667	0.668	0.679	0.677	0.680	0.677	n.a	0.674	0.667	0.666	0.666
Tags-LL	3550.9	3550.5	3551.2	3572.5	3558.9	3549.5	3547.9	n.a	3549.6	3550.5	3552.5	3551.3
CPUE-Lswitch	1	1	1	1	1	1	1	1	0	1	1	1
CPUE-weight	3.00	3	3	3	3	3	3	3	n.a	3	3	3
CPUE-sdnr	0.975	0.978	0.977	1.322	1.064	0.973	0.976	0.979	n.a	0.972	1.121	0.976
CPUE-MAR	0.692	0.681	0.701	0.747	0.675	0.651	0.776	0.597	n.a	0.667	0.779	0.682
CPUE-LL	-79.7	-79.48	-79.55	-54.16	-73.85	-79.79	-79.64	-79.42	n.a	-79.85	-69.88	-79.62
CR-Lswitch	1	1	1	1	1	1	1	1	1	0	1	1
CR-weight	3.00	3	3	3	3	3	3	3	3	n.a	3	3
CR-sdnr	0.766	0.756	0.765	1.087	1.178	0.611	0.818	0.625	0.889	n.a	0.754	0.759
CR-MAR	0.535	0.528	0.531	0.652	0.706	0.467	0.558	0.388	0.627	n.a	0.514	0.526
CR-LL	34.8	34.70	34.77	38.05	39.18	33.61	35.23	33.70	35.90	n.a	34.68	34.72
Poo-Lswitch	0	0	0	0	0	0	0	0	0	0	1	0
Poo-weight	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.0	n.a
Poo-sdnr	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.884	n.a
Poo-MAR	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.560	n.a
Poo-LL	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	-20.99	n.a
Priors	-38.8	-39.1	-38.8	-26.9	-32.4	-40.0	-39.8	-39.8	-45.0	-42.2	-36.2	-37.8
Function value	3622.7	3590	3624	4303	3644	3618	3464	59.49	3683	3584	3620	3621
ln(*R0*)	15.191	15.197	15.221	14.620	14.460	15.204	15.148	15.370	15.157	15.168	15.415	15.141
M	0.291	0.294	0.295	0.170	0.16*	0.288	0.291	0.350	0.270	0.281	0.317	0.285
ln(*qCPUE*)	-6.539	-6.486	-6.538	-6.218	-6.336	-6.617	-6.829	-6.350	-6*	-6.538	-6.572	-5.335
ln(*qCR*)	-2.650	-2.587	-2.647	-2.604	-2.733	-2.579	-2.990	-2.567	-2.991	-3*	-2.652	-2.525
ln(*qpuerulus*)	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-15.37	-6*
CPUEpow	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	0.833

	base1	No logs sens1	No trunc sens2	LF20 sens3	M0.16 sens4	domed sens5	No LFs sens6	No tags sens7	No CPUE sens8	No CR sens9	poo sens10	pow sens11
mat50	62.73	62.1	62.8	61.2	62.8	61.2	50*	59.4	61.1	62.7	62.6	63.1
mat95add	13.98	13.11	13.92	10.33	13.84	13.41	14*	11.32	12.71	13.92	13.37	13.96
Galpha_M	3.226	3.249	3.223	3.122	3.290	3.243	3.334	3.999	3.181	3.221	3.107	3.233
GBeta_M	1.998	1.953	2.033	2.575	1.842	1.958	1.350	3.999	2.070	1.991	2.111	2.028
Gdiff_M	0.619	0.601	0.631	0.825	0.560	0.604	0.405	1.000	0.651	0.618	0.679	0.627
Gshape_M	5.608	5.65	5.59	5.52	5.89	5.60	5.51	4.90	5.55	5.67	5.39	5.60
GrowthCV_M	0.400	0.399	0.400	0.396	0.396	0.400	0.396	0.5*	0.409	0.403	0.421	0.399
Galpha_F	3.043	2.985	3.058	2.070	2.129	3.132	3.423	3.480	3.187	3.002	3.063	3.047
GBeta_F	1.212	1.191	1.218	1.663	1.313	1.118	0.763	2.114	1.111	1.210	1.219	1.216
Gdiff_F	0.398	0.399	0.398	0.804	0.617	0.357	0.223	0.607	0.349	0.403	0.398	0.399
Gshape_F	5.657	5.55	5.68	4.77	4.84	5.64	5.21	5.07	5.79	5.65	5.56	5.66
GrowthCV_F	0.633	0.640	0.631	0.672	0.732	0.600	0.582	0.5*	0.585	0.637	0.617	0.631
vuln1	0.770	0.740	0.752	0.679	0.707	0.845	0.675	1.000	0.645	0.762	0.753	0.702
vuln2	0.564	0.556	0.546	0.551	0.576	0.613	0.478	0.750	0.787	0.560	0.542	0.536
vuln3	0.014	0.011	0.014	0.013	0.021	0.018	0.010	0.018	0.011	0.014	0.013	0.012
vuln4	0.731	0.659	0.725	0.701	0.746	0.734	1.000	0.769	0.418	0.731	0.731	0.667
VL1_M	7.15	7.30	7.07	6.12	8.72	7.28	4*	6.96	6.13	7.24	6.77	7.05
VR1_M	200*	200*	200*	200*	200*	8.08	200*	200*	200*	200*	200*	200*
SelectMax1_M	57.16	57.47	57.06	55.31	58.91	57.26	54*	57.82	56.54	57.18	57.10	57.26
VL1_F	7.69	5.22	7.43	8.39	23.61	9.63	7*	9.13	6.12	7.71	8.80	7.93
VR1_F	200*	200*	200*	200*	200*	12.26	200*	200*	200*	200*	200*	200*
SelectMax1_F	49.02	44.61	48.61	52.15	74.77	51.97	60*	53.57	46.29	49.01	51.16	49.41
VL2_M	5.15	5.27	5.14	5.25	5.41	5.15	4*	4.94	5.15	5.16	5.10	5.17
VR2_M	200*	200*	200*	200*	200*	20.26	200*	200*	200*	200*	200*	200*
SelectMax2_M	56.38	56.43	56.38	56.45	56.13	56.35	54*	56.60	56.35	56.31	56.50	56.46
VL2_F	12.37	13.36	12.23	12.79	11.73	13.47	7*	10.89	14.08	12.42	12.42	12.57
VR2_F	200*	200*	200*	200*	200*	25.96	200*	200*	200*	200*	200*	200*
SelectMax2_F	66.67	67.02	66.81	67.80	68.00	68.70	60*	66.03	66.28	66.67	66.97	66.74
Bcurr/Bref	1.909	1.87	1.91	1.86	1.66	1.78	1.93	1.73	1.08	1.90	1.73	2.02
Bref	428.5	410.3	427.7	283.1	384.0	496.1	564.8	417.2	637.5	430.8	441.9	350.3
Bmsy	404.7	393.0	394.6	521.4	551.4	451.8	489.3	439.5	342.9	422.1	379.6	365.1
MSY	645.1	641.8	650.5	540.2	551.4	679.6	663.9	637.7	691.3	661.7	653.8	633.7
Fmult	3.340	3.220	3.470	1.270	1.450	3.400	3.640	2.780	3.490	3.240	3.480	3.090
Yrs 32 to MLS_M	4.0	4	4	4.5	4	4	3.5	4	4	4	4.5	4
Yrs 32 to MLS_F	6.5	6.5	6.5	10.5	10	6	6	6	6	6.5	6.5	6.5

Table 7: MPD sensitivity trials (see list above) based on initial base case *base2*. Grey indicates items where a dataset was not used or a parameter was fixed at the value shown; an asterisk indicates that it was fixed.

		No	No				No	No	No	No		
		logs	trunc	LF20	M0.16	domed	LFs	tags	CPUE	CR	poo	pow
	base2	sens1	sens2	sens3	sens4	sens5	sens6	sens7	sens8	sens9	sens10	sens11
LFs-Lswitch	1	1	1	1	1	1	0	1	1	1	1	1
LFs-weight	3.50	3.50	3.50	20.00	3.50	3.50	n.a	3.50	3.50	3.50	3.50	3.50
LFs-sdnr	1.093	1.171	1.128	2.800	1.474	1.070	n.a	1.145	1.056	1.080	1.086	1.108
LFs-MAR	0.138	0.136	0.131	0.307	0.132	0.135	n.a	0.123	0.135	0.138	0.139	0.136
LFs-LL	168.7	136.0	170.4	847.4	165.0	167.2	n.a	157.4	151.0	169.2	172.3	166.9
Tags-Lswitch	1	1	1	1	1	1	1	0	1	1	1	1
Tags-weight	0.80	0.80	0.80	0.80	0.80	0.80	0.80	n.a	0.80	0.80	0.80	0.80
Tags-sdnr	1.255	1.261	1.256	1.221	1.265	1.252	1.273	n.a	1.259	1.254	1.251	1.251
Tags-MAR	0.668	0.673	0.666	0.655	0.669	0.663	0.676	n.a	0.671	0.666	0.665	0.660
Tags-LL	3551.1	3550.9	3551.2	3580.4	3561.1	3551.7	3548.7	n.a	3549.5	3550.0	3552.2	3552.3
CPUE-Lswitch	1	1	1	1	1	1	1	1	0	1	1	1
CPUE-weight	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	n.a	4.00	4.00	4.00
CPUE-sdnr	1.205	1.204	1.204	1.482	1.309	1.213	1.292	1.210	n.a	1.203	1.385	1.205
CPUE-MAR	0.701	0.666	0.730	0.855	0.846	0.703	0.963	0.691	n.a	0.706	0.991	0.738
CPUE-LL	-82.1	-82.1	-82.1	-58.2	-73.7	-81.5	-75.1	-81.7	n.a	-82.2	-67.1	-82.0
CR-Lswitch	1	1	1	1	1	1	1	1	1	0	1	1
CR-weight	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	n.a	4.00	4.00
CR-sdnr	0.720	0.701	0.719	0.738	0.948	0.663	0.847	0.619	0.850	n.a	0.722	0.715
CR-MAR	0.536	0.512	0.549	0.492	0.649	0.503	0.649	0.380	0.723	n.a	0.648	0.524
CR-LL	31.2	31.1	31.2	31.4	33.3	30.8	32.3	30.5	32.4	n.a	31.3	31.2
Poo-Lswitch	0	0	0	0	0	0	0	0	0	0	1	0
Poo-weight	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.00	n.a
Poo-sdnr	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.107	n.a
Poo-MAR	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.638	n.a
Poo-LL	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	-14.8	n.a
Priors	-36.0	-37.2	-36.1	-32.5	-25.3	-36.6	-35.6	-39.0	-42.0	-40.8	-35.1	-35.6
Function value	3633.0	3598.7	3634.6	4368.4	3660.5	3631.6	3470.4	67.2	3690.9	3596.1	3638.8	3632.8
ln(*R0*)	15.183	15.181	15.214	15.091	14.412	15.123	15.133	15.320	15.129	15.184	15.418	15.137
M	0.301	0.299	0.305	0.252	0.16*	0.287	0.290	0.350	0.274	0.294	0.324	0.294
ln(*qCPUE*)	-6.582	-6.475	-6.602	-6.437	-6.267	-6.554	-6.891	-6.318	-6*	-6.586	-6.579	-6.044
ln(*qCR*)	-2.475	-2.350	-2.496	-2.447	-2.371	-2.436	-3.074	-2.374	-3.204	-3*	-2.443	-2.382
ln(*qpuerulus*)	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-6*	-15.380	-6*
CPUEpow	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	0.930
mat50	38.54	39.04	38.53	45.42	49.33	39.06	39*	42.87	36.67	38.59	39.20	38.93
mat95add	13.84	13.83	13.82	18.22	16.25	13.86	17*	14.53	13.79	13.85	13.92	13.85
Galpha_M	3.277	3.292	3.273	3.162	3.325	3.301	3.361	4.141	3.210	3.266	3.142	3.282
GBeta_M	1.933	1.883	1.971	2.694	1.799	1.870	1.324	4.141	2.006	1.926	2.063	1.925
Gdiff_M	0.590	0.572	0.602	0.852	0.541	0.567	0.394	1.000	0.625	0.590	0.657	0.587
Gshape_M	5.748	5.714	5.736	5.319	5.784	5.719	5.496	4.909	5.611	5.861	5.417	5.746
GrowthCV_M	0.397	0.393	0.397	0.389	0.389	0.393	0.391	0.5*	0.403	0.402	0.416	0.394
Galpha_F	3.095	3.018	3.137	2.622	2.100	3.007	3.453	3.505	3.214	3.090	3.080	3.030
GBeta_F	1.236	1.204	1.228	1.616	1.372	1.260	0.748	2.493	1.122	1.219	1.238	1.284
Gdiff_F	0.399	0.399	0.391	0.616	0.653	0.419	0.217	0.711	0.349	0.395	0.402	0.424
Gshape_F	5.772	5.505	5.763	4.791	4.677	5.805	5.034	4.968	5.902	5.798	5.667	5.785

	base2	No logs sens1	No trunc sens2	LF20 sens3	M0.16 sens4	domed sens5	No LFs sens6	No tags sens7	No CPUE sens8	No CR sens9	poo sens10	pow sens11
GrowthCV_F	0.645	0.638	0.633	0.764	0.746	0.670	0.573	0.5*	0.627	0.642	0.630	0.667
vuln1	0.783	0.718	0.780	0.831	0.668	0.790	0.689	0.995	1.000	0.769	0.741	0.742
vuln2	0.558	0.533	0.552	0.604	0.546	0.566	0.508	0.753	1.000	0.548	0.519	0.538
vuln3	0.760	0.688	0.755	0.768	0.790	0.769	1.000	0.821	0.551	0.766	0.757	0.737
vuln4	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*
VL1_M	7.68	7.80	7.60	6.08	9.28	7.84	4*	7.55	5.83	7.83	7.06	7.68
VR1_M	200*	200*	200*	200*	200*	7.91	200*	200*	200*	200*	200*	200*
SelectMax1_M	58.09	58.45	57.98	55.74	60.00	58.25	54*	59.17	55.43	58.11	57.69	58.19
VL1_F	16.14	15.85	16.14	10.94	12.64	16.17	7*	12.62	11.68	16.23	15.65	15.90
VR1_F	200*	200*	200*	200*	200*	45.74	200*	200*	200*	200*	200*	200*
SelectMax1_F	80.00	80.00	80.00	70.19	75.35	80.00	60*	73.78	69.26	80.00	80.00	80.00
VL2_M	5.16	5.29	5.15	5.08	5.43	5.17	4*	4.96	5.19	5.17	5.14	5.18
VR2_M	200*	200*	200*	200*	200*	18.58	200*	200*	200*	200*	200*	200*
SelectMax2_M	56.22	56.32	56.22	56.51	56.19	56.19	54*	56.56	56.40	56.13	56.45	56.25
VL2_F	8.07	8.15	7.99	7.49	8.33	8.10	7*	7.13	8.02	8.14	8.07	8.05
VR2_F	200*	200*	200*	200*	200*	52.79	200*	200*	200*	200*	200*	200*
SelectMax2_F	68.36	68.45	68.32	67.26	69.07	68.39	60*	66.43	66.57	68.45	68.84	68.42
Bcurr/Bref	1.809	1.770	1.813	1.985	1.587	1.749	1.911	1.597	1.162	1.808	1.716	1.851
Bref	474.2	431.4	482.7	356.3	375.2	475.1	595.6	444.6	896.9	477.8	464.3	427.8
Bmsy	396.9	374.0	394.5	437.0	493.9	412.5	512.8	440.6	486.6	416.8	362.2	377.5
MSY	655.3	646.9	662.7	589.6	523.1	658.3	654.6	634.6	689.1	684.3	669.8	644.7
Fmult	3.670	3.410	3.830	2.390	1.440	3.410	3.610	2.680	3.750	3.630	3.880	3.460
Yrs 32 to MLS_M	4.0	4.0	4.0	4.5	4.0	4.0	3.5	4.0	4.0	4.0	4.5	4.0
Yrs 32 to MLS_F	6.0	6.5	6.0	8.0	10.0	6.5	6.0	6.0	6.0	6.0	6.5	6.5

4. Final base case McMC

Two million McMC simulations were made, starting at the MPD value and saving 1000 samples. The *GrowthCV* parameter was estimated in the MPD and then fixed to their estimated values during the McMC. The estimated and derived parameter traces are shown in Figure 26: these were acceptable except for the maximum selectivity for females in epoch 1, which was on the upper bound in the MPD and for which the model had very little data.

Diagnostic plots are shown in Figure 27 and the posteriors are shown in Figure 28. The McMC appears to be well mixed and converged. Most of the MPD estimates were near the centre of the posterior.

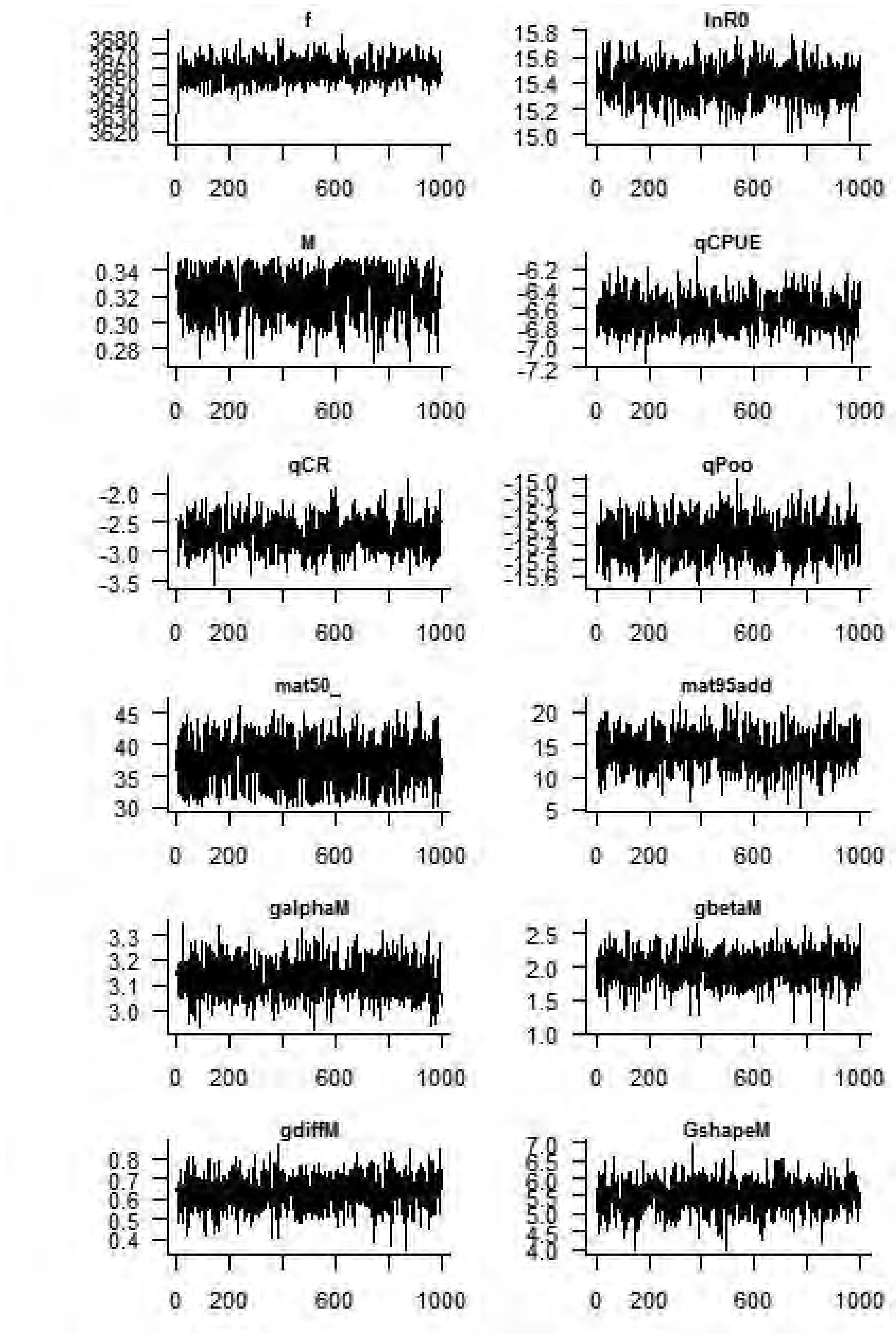

Figure 26: Traces from the final base case McMC.

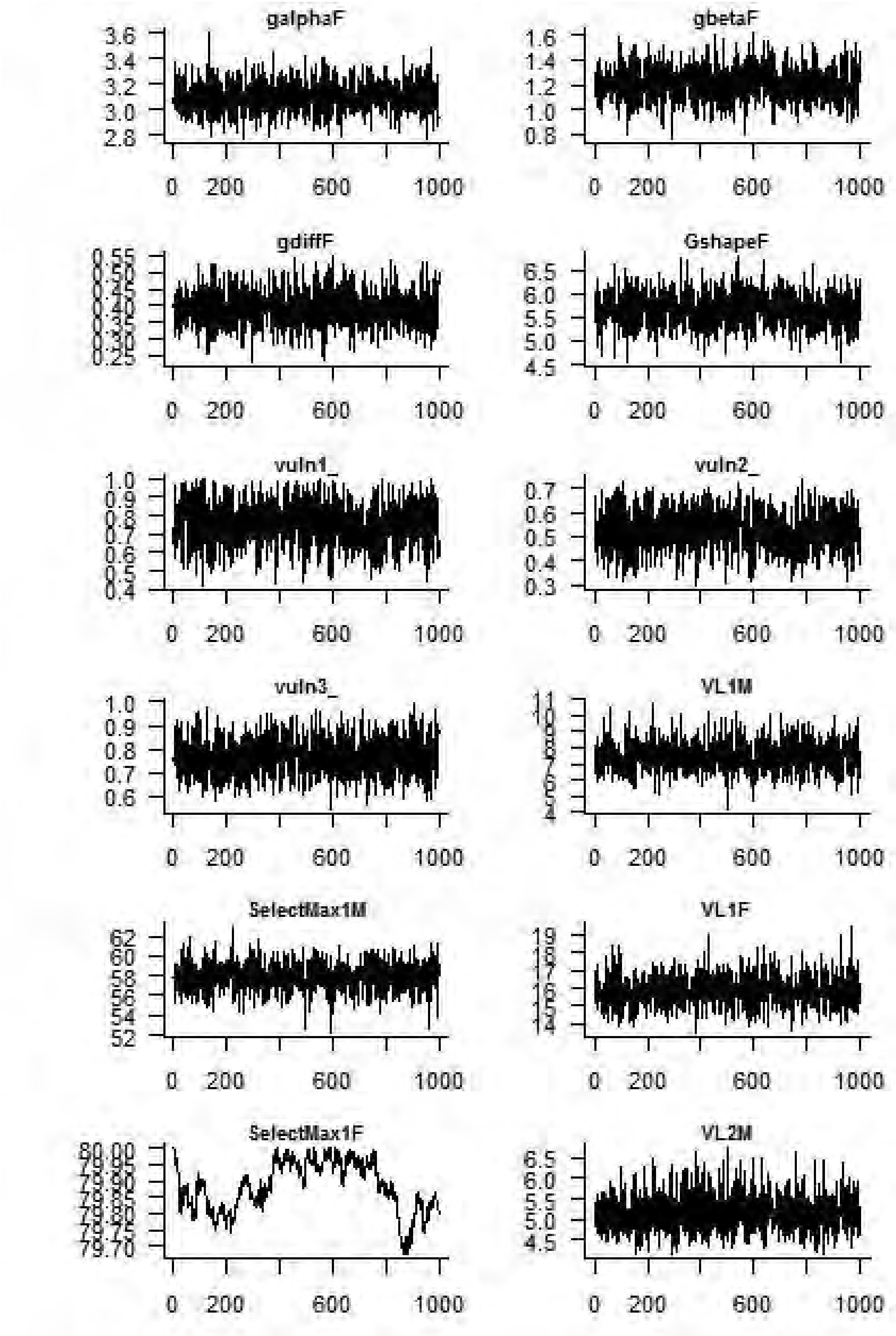

Figure 26: Traces from the final base case McMC.

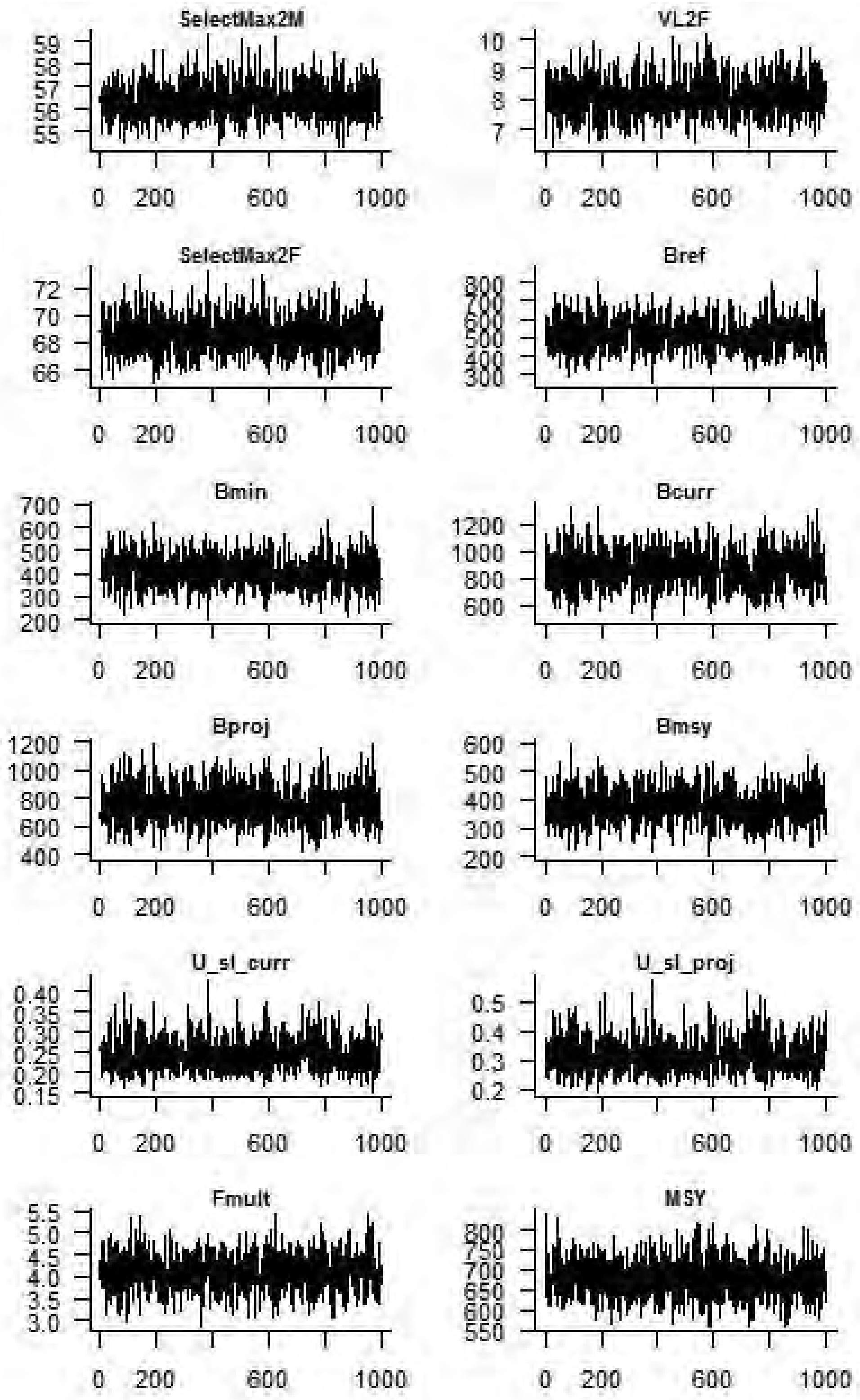

Figure 26: Traces from the final base case McMC.

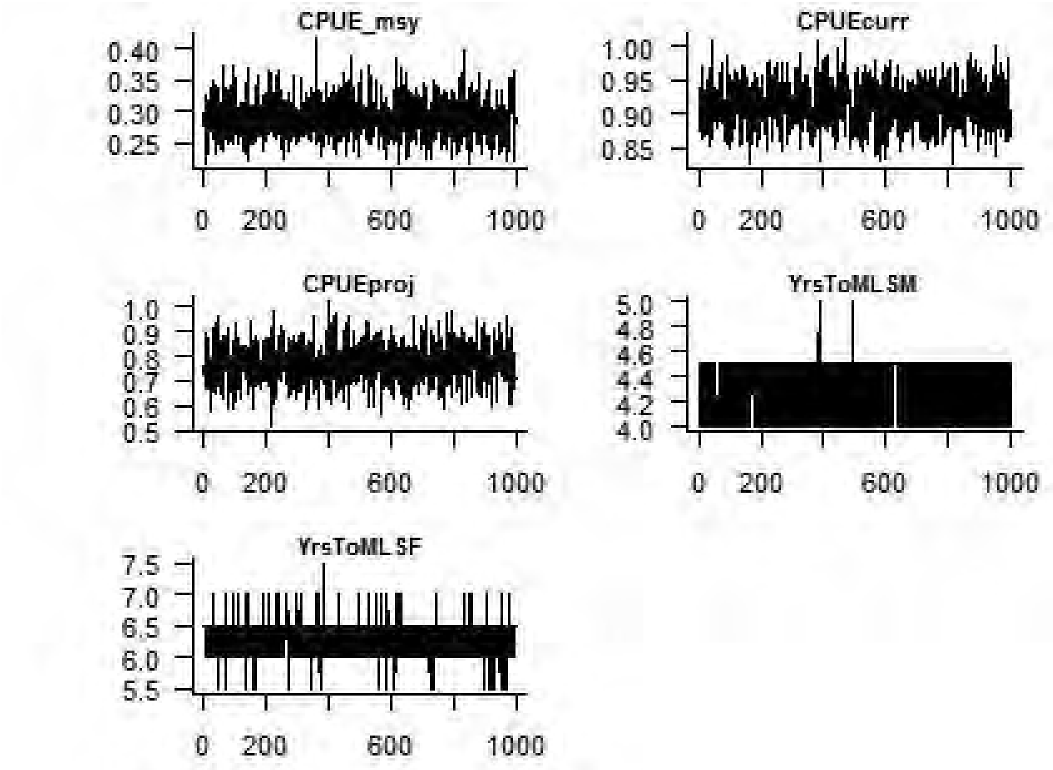

Figure 26: Traces from the final base case McMC.

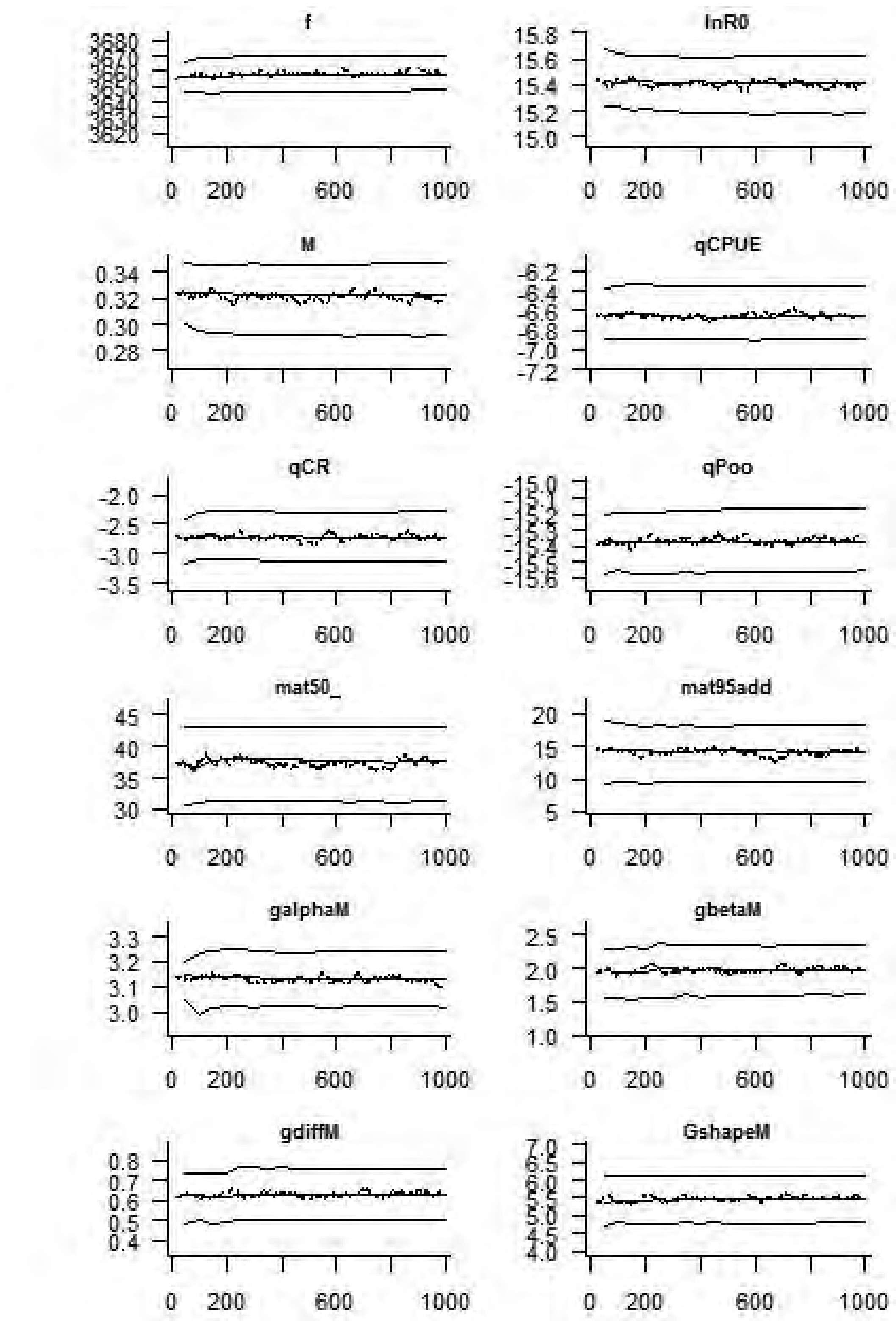

Figure 27: Diagnostic plots for the estimated and derived parameters from the final base case McMC. The dotted lines shows the moving mean over 50 samples, and the other lines show the running median and 5th and 95th quantiles of the posterior distribution.

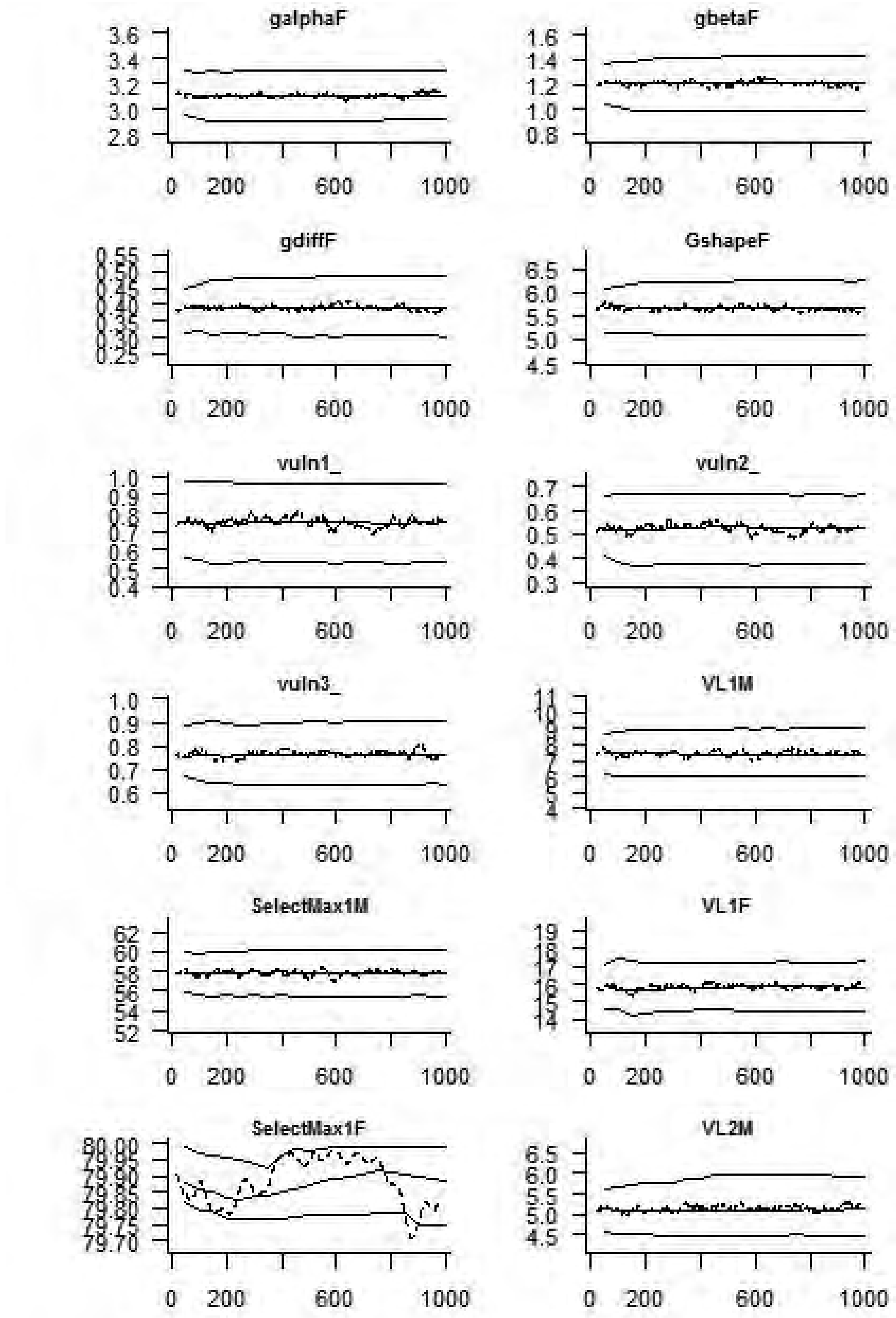

Figure 27 continued: Diagnostic plots.

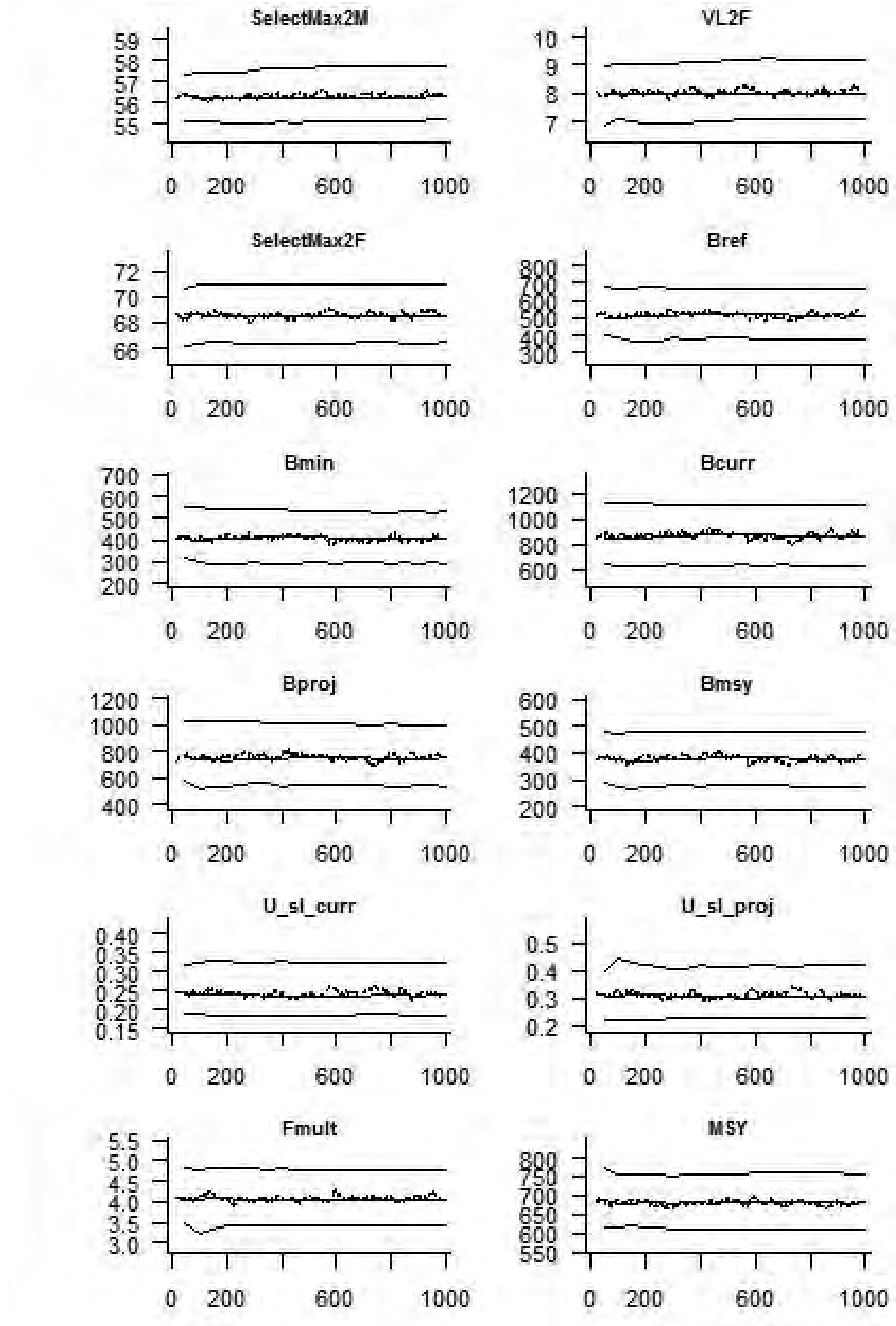

Figure 27 continued: Diagnostic plots.

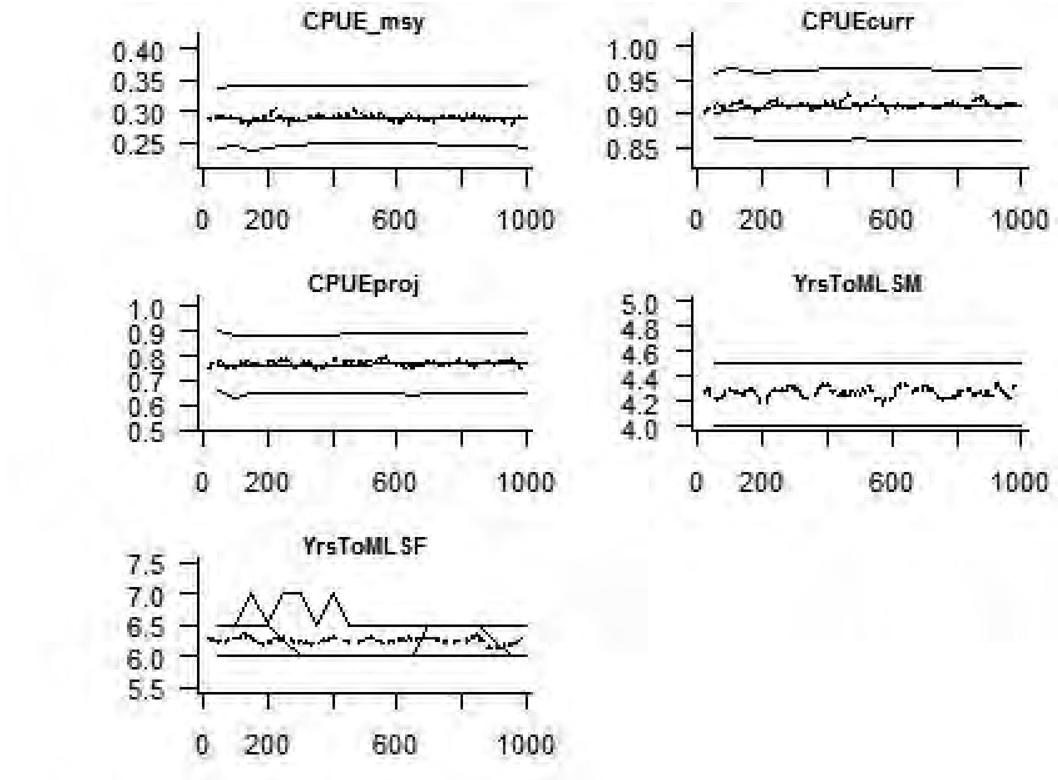

Figure 27 continued: Diagnostic plots.

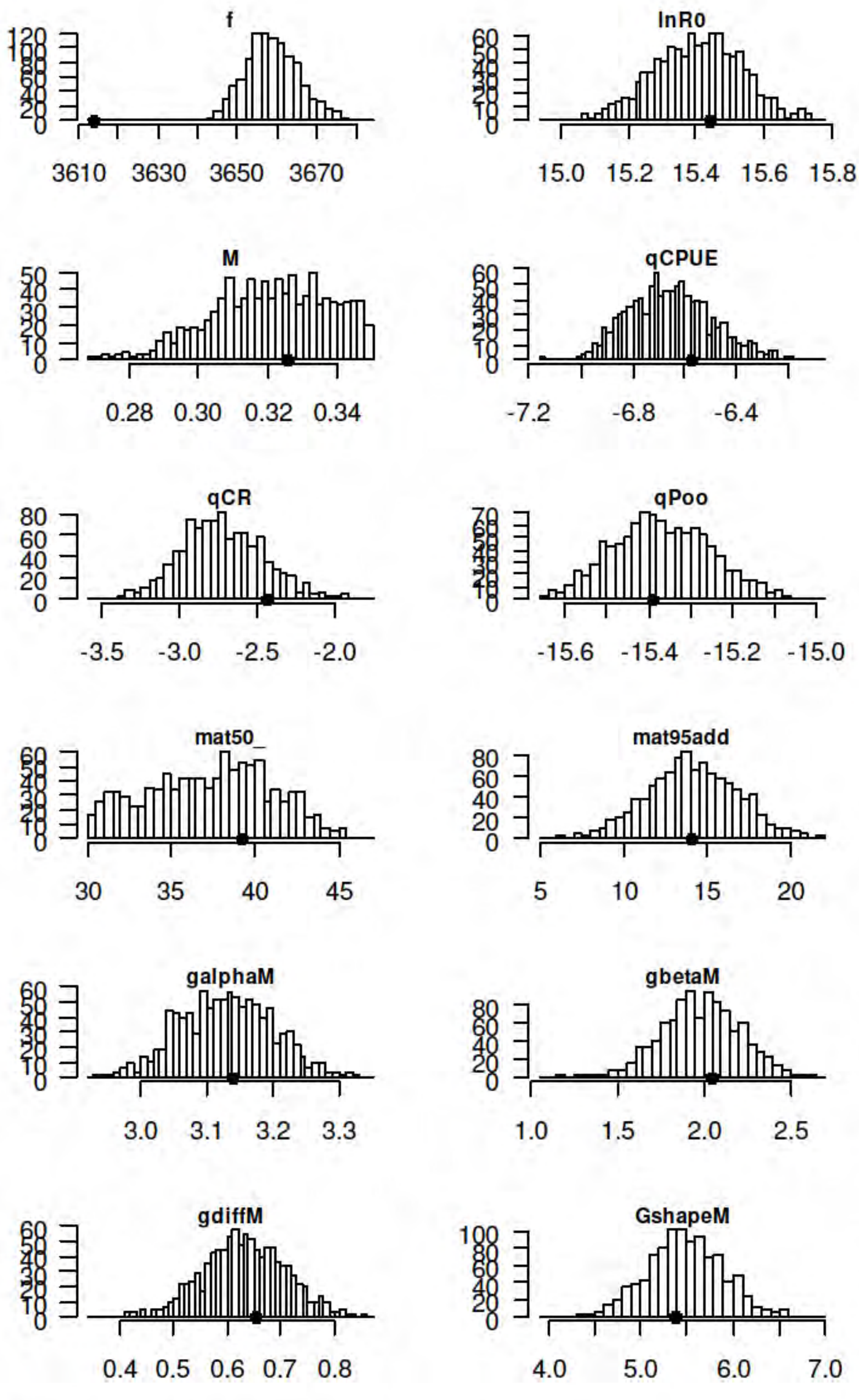

Figure 28: The posterior distributions of estimated and derived parameters from the final base case McMC. The dots show the MPD estimate.

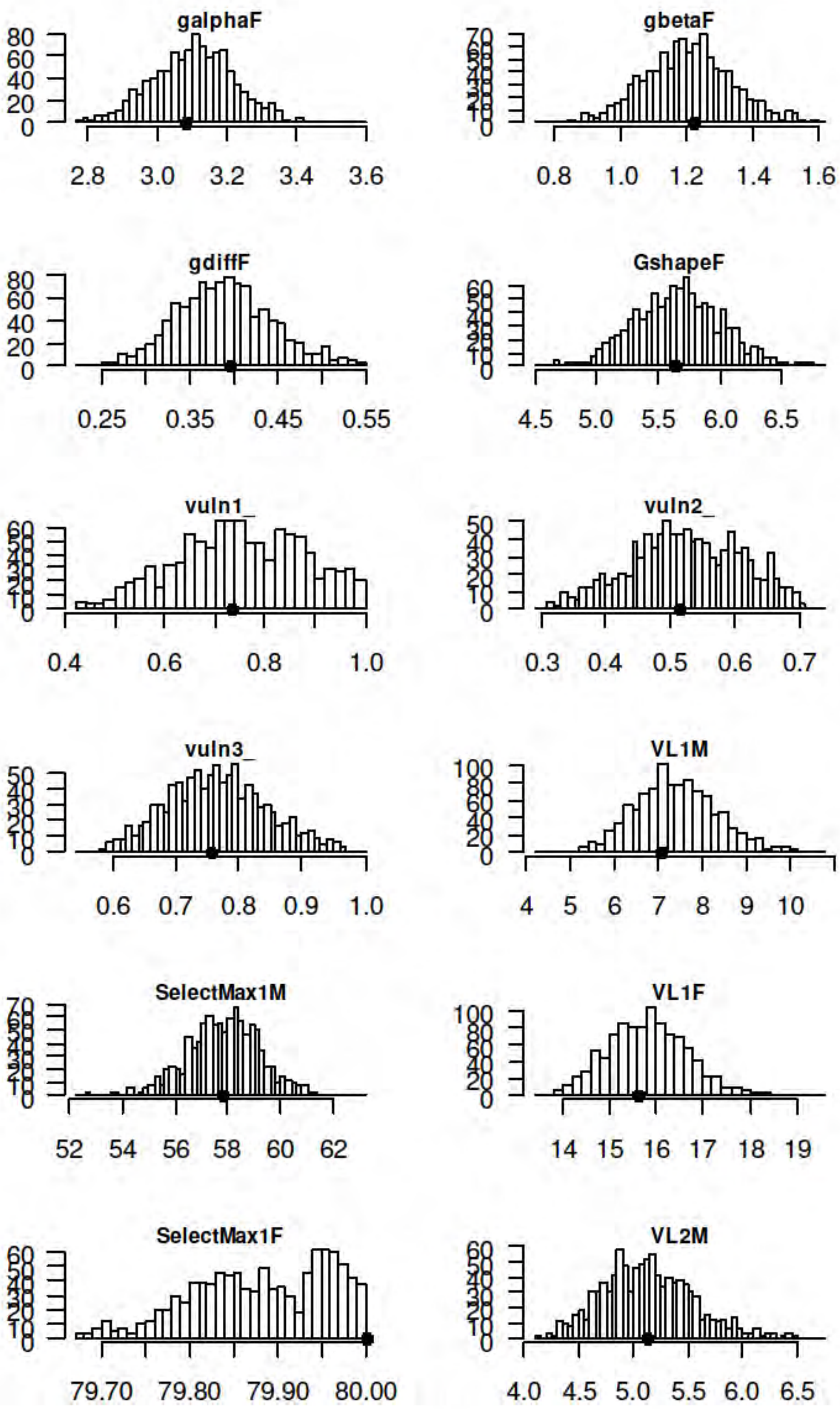

Figure 28 continued: The posterior distributions of estimated and derived parameters.

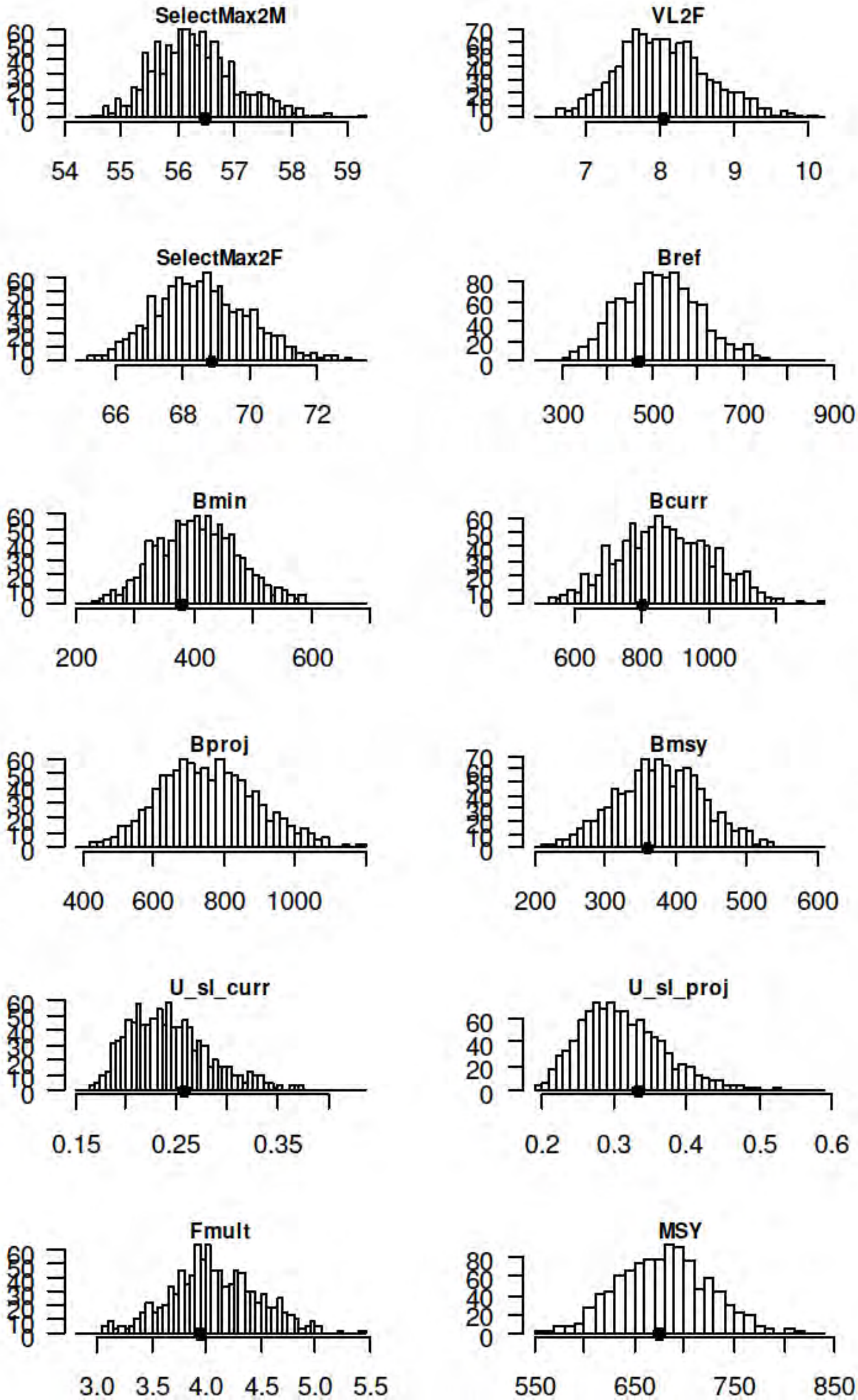

Figure 28 continued: The posterior distributions of estimated and derived parameters.

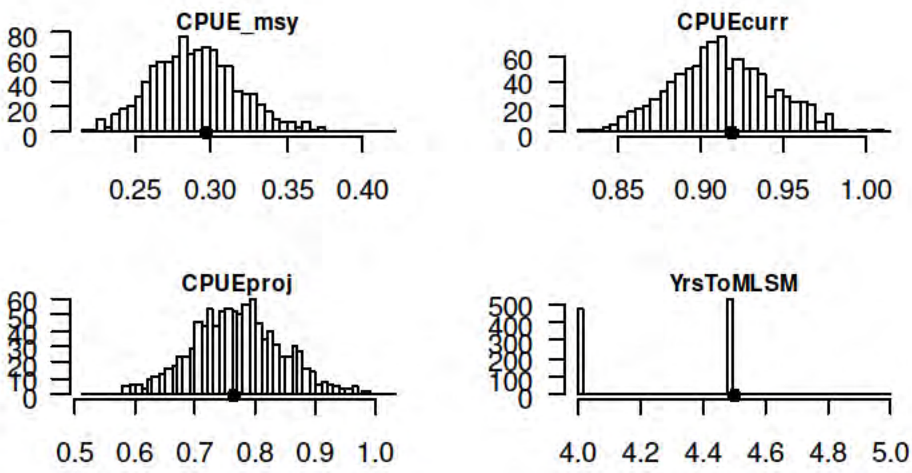

Figure 28 continued: The posterior distributions of estimated and derived parameters.

The fits to CPUE and CR in the McMC are shown in Figure 29 and Figure 30; the *Rdev* trajectory in Figure 31 and recruitment trajectory in Figure 32, vulnerable biomass trajectory in Figure 33, exploitation rate trajectories in Figure 34 and surplus production in Figure 35. Fits to CPUE and CR appear good, although the model under-estimated the SS CPUE values in the most recent two years. There was much variability in the early *Rdev*s and less variation in the more recent ones, probably reflecting availability of data in the model; the pattern of lows and highs seemed well determined. Surplus production followed recruitment. In the exploitation rate plots, the AW rate is the annual rate before 1979 (the model was fitted to annual data before 1979), explaining the sudden shift at 1979.

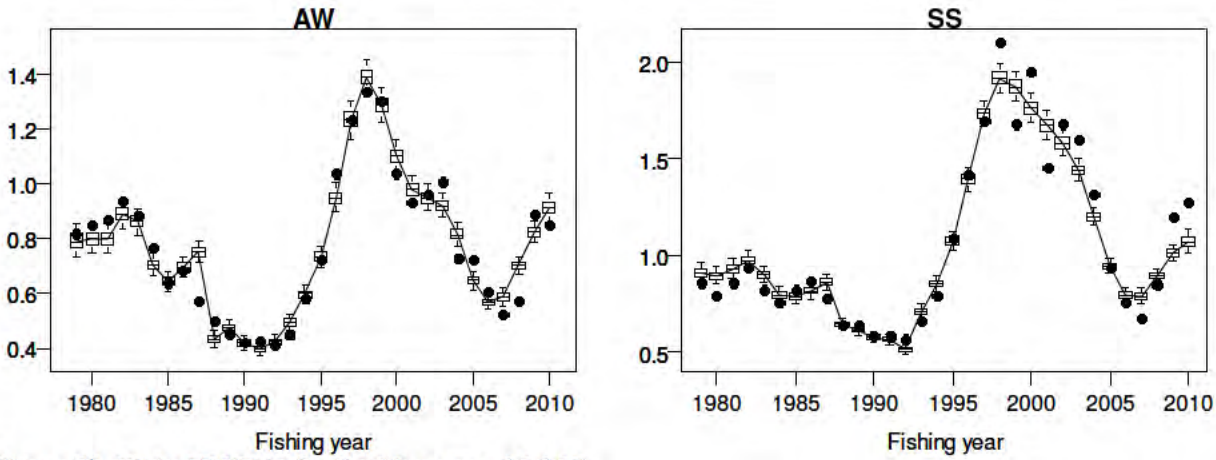

Figure 29: Fit to CPUE in the final base case McMC.

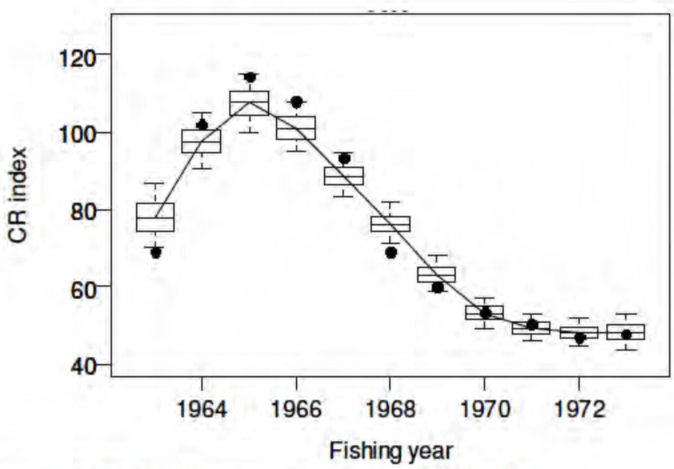

Figure 30: Fit to CR in the final base case McMC.

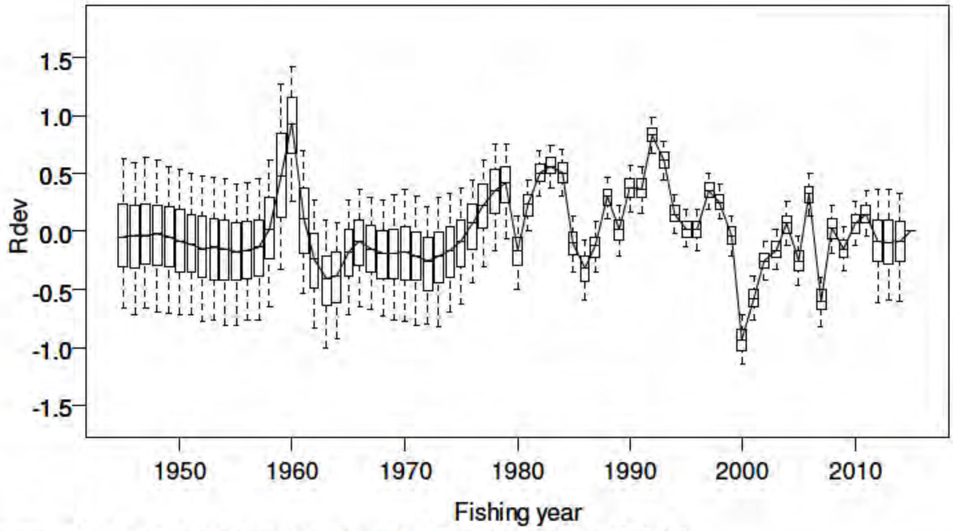

Figure 31: The *Rdev* trajectory from the final base case McMC.

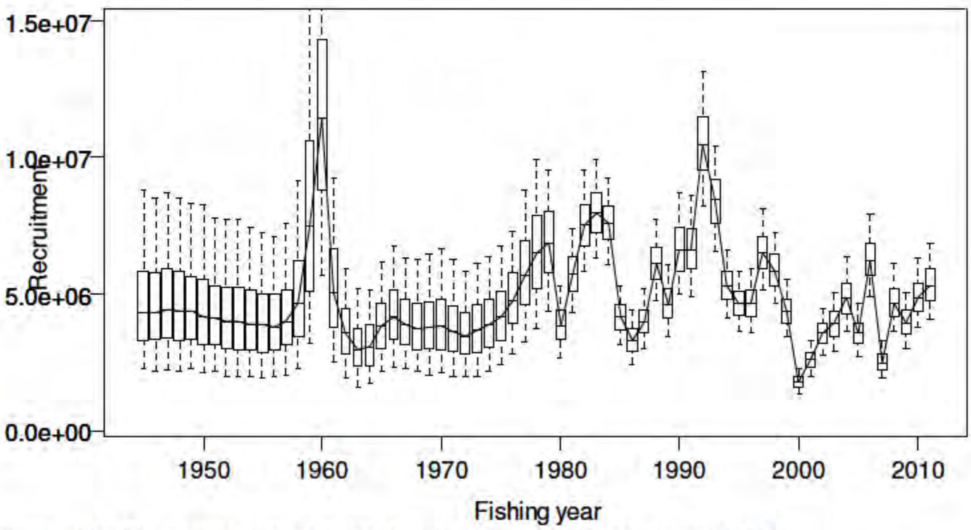

Figure 32: The recruitment trajectory from the final base case McMC.

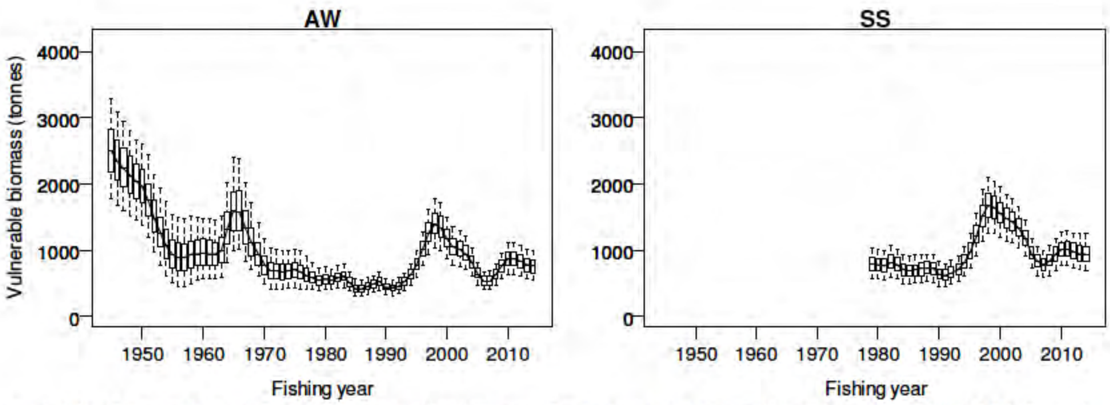

Figure 33: The vulnerable biomass trajectory (calculated for this plot using the 2010 MLS and selectivity) from the final base case McMC.

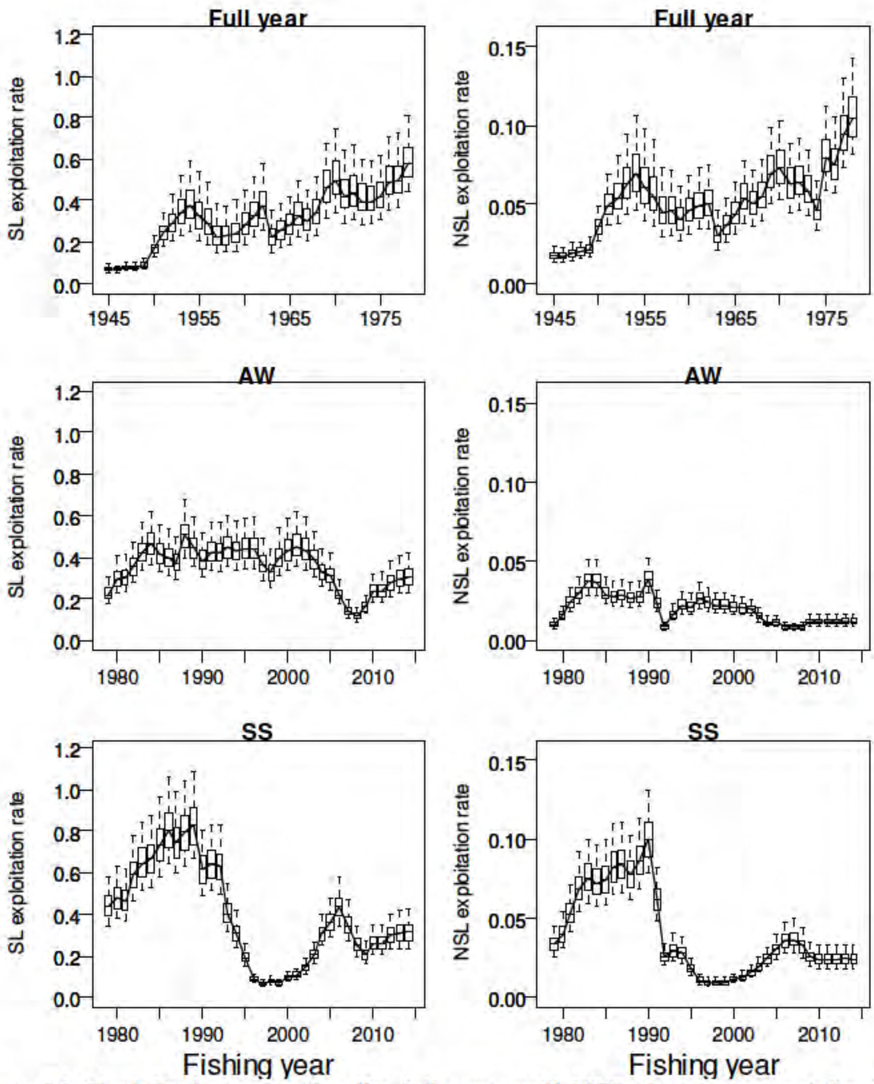

Figure 34: Exploitation rates (for the full year until 1979, then by season) for the SL (left) and NSL fisheries from the final base case McMC.

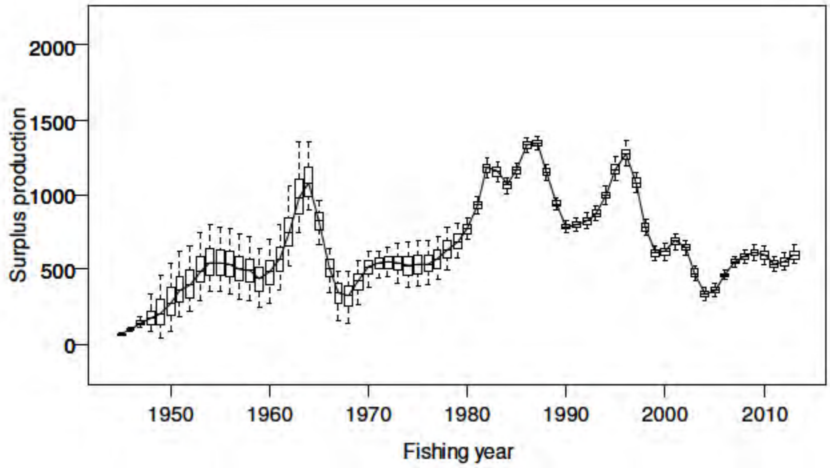

Figure 35: The trajectory of surplus production from the final base case McMC.

Posterior distributions of the estimated parameters are summarised in Table 8. Parameters showing the highest variation (a range between the 5th and 95th quantiles greater than 50% of the median) were *mat95add* (for which there were few data), *vuln1* and *vuln2*; the growth parameters showed up to 47% variation and the remaining parameters were less variable. Most of the posterior medians were within a few percent of the MPD, with ln(*qCR*) being the only exception at 11%.

Table 8: Summaries of posterior distributions of estimated parameters in the final base case McMC.

	Min	0.05	Median	Mean	0.95	Max	MPD
function value	3613.7	3648.1	3658.4	3658.8	3670.7	3682.3	3613.6
ln(R0)	14.95	15.18	15.41	15.41	15.62	15.77	15.44
M	0.269	0.291	0.322	0.321	0.346	0.350	0.326
ln(qCPUE)	-7.16	-6.90	-6.66	-6.66	-6.36	-6.08	-6.57
ln(qCR)	-3.56	-3.14	-2.74	-2.72	-2.28	-1.76	-2.44
ln(qpuerulus)	-15.66	-15.56	-15.37	-15.37	-15.16	-14.99	-15.39
mat50	30.04	31.25	37.67	37.34	43.08	46.93	39.17
mat95add	5.355	9.533	14.012	14.087	18.232	21.670	13.935
Galpha_M	2.92	3.02	3.13	3.13	3.24	3.35	3.14
GBeta_M	1.06	1.61	1.98	1.98	2.35	2.65	2.05
Gdiff_M	0.34	0.51	0.63	0.63	0.76	0.87	0.65
Gshape_M	3.95	4.80	5.47	5.48	6.14	6.94	5.37
Galpha_F	2.76	2.91	3.11	3.11	3.30	3.60	3.08
GBeta_F	0.76	0.99	1.20	1.21	1.43	1.62	1.22
Gdiff_F	0.23	0.30	0.39	0.39	0.48	0.55	0.40
Gshape_F	4.54	5.09	5.66	5.66	6.24	6.80	5.63
vuln1	0.421	0.535	0.751	0.753	0.960	1.000	0.733
vuln2	0.299	0.378	0.525	0.525	0.662	0.737	0.513
vuln3	0.547	0.638	0.765	0.766	0.908	0.998	0.755
VL1_M	4.22	5.98	7.38	7.42	9.02	10.78	7.07
SelectMax1_M	52.31	55.53	57.93	57.85	60.13	63.10	57.75
VL1_F	13.55	14.50	15.82	15.83	17.26	19.51	15.57
SelectMax1_F	79.67	79.75	79.89	79.88	79.99	80.00	80.00
VL2_M	4.13	4.49	5.12	5.15	5.92	6.72	5.11
SelectMax2_M	54.29	55.20	56.27	56.32	57.72	59.28	56.47
VL2_F	6.40	7.07	8.00	8.04	9.19	10.14	8.01
SelectMax2_F	65.00	66.43	68.50	68.59	70.97	73.27	68.80

5. Stock assessment

5.1 Short-term projection methodology

As part of the stock assessment, short-term projections were made from each of the 1000 samples of the joint posterior distribution of parameters; these were made for four years to 2014. Projections were made using the 2011–12 TACC and 2010 levels of non-commercial catch (Table 9). The seasonal split for commercial catch was as in 2010–11; illegal catch used the same split as commercial; recreational and customary were each 90% SS and 10% AW. These splits were continued through the projection years. Recruitment was resampled from 2002 through 2011.

Table 9: Projection catches (t). SL = commercial + recreational - reported illegal; NSL = reported illegal + unreported illegal + customary

Source	Value
Commercial	466.9
Recreational	58.6
Customary	20.0
Reported illegal	5.3
Unreported illegal	34.7
SL	520
NSL	60

5.2 Assessment indicators

Indicators for the assessment are shown in Table 10. *Bmin* was the minimum beginning of season AW vulnerable biomass estimated by the model and *Bproj* was the beginning season AW vulnerable biomass in the final projection year. *Bref* was the average beginning season AW vulnerable biomass over the period 1979–1988. *Bmsy* was the biomass (beginning of season AW vulnerable biomass) associated with the maximum yield *MSY* (annual SL catch), and the multiplier *Fmult* was the multiplier that produced *MSY*. *Bmsy* was calculated by making a series of forward projections for 50 years, using deterministic recruitment at *R0* and using a multiplier on the estimated current *F* value for the size-limited (SL) fishery in the AW and SS seasons. In this simulation, the ratio of *F* for the two seasons was fixed at its current values and the NSL catch fixed at 2010 values. The multiplier that gave *Bmsy* was termed *Fmult*. Spawning biomass, *SSB*, was the weight of mature females at the start of AW, hence *SSBmsy*, *SSBcurrent* and *SSBproj*.

The assessment suggested that current biomass was about twice *Bmin*, more than twice *Bmsy* (*Bmsy* is slightly less than *Bmin*) and about 160% of *Bref*, with no chance that it lay below any of these indicators. *Bref* was larger than *Bmsy* with 100% certainty, and had a median 36% larger than *Bmsy*. The assessment suggested that *SSB* was over half its unfished level and very close to *SSBmsy*.

The assessment suggested that vulnerable biomass would decline by 13% over the next four years, but would still be well above *Bref* and *Bmsy* with 100% certainty. The probability of short-term decline was very high, with only 1% chance that the vulnerable biomass would increase.

Table 10: Assessment indicators from the final base case McMC.

CRA 4	Median	5th quantile	95th quantile
Bmin	407.1	294.3	529.5
Bcurr	861.6	630.4	1112.5
Bref	513.8	377.3	667.8
Bproj	751.3	540.4	999.6
Bmsy	377.4	275.8	481.5
MSY	679.9	606.9	758.4
Fmult	4.05	3.42	4.78
SSBcurr	2615.2	2254.0	3005.3
SSBproj	2795.5	2366.4	3321.9
SSBmsy	2645.7	2242.7	3132.2
CPUEcurrent	0.912	0.860	0.967
CPUEproj	0.768	0.645	0.894
CPUEmsy	0.289	0.243	0.341
Bcurr/Bmin	2.118	1.880	2.459
Bcurr/Bref	1.683	1.498	1.884
Bcurr/Bmsy	2.296	1.985	2.651
Bproj/Bcurr	0.873	0.781	0.964
Bproj/Bref	1.464	1.243	1.716
Bproj/Bmsy	2.012	1.644	2.379
SSBcurr/SSB0	0.647	0.574	0.726
SSBproj/SSB0	0.690	0.596	0.801
SSBcurr/SSBmsy	0.981	0.877	1.107
SSBproj/SSBmsy	1.050	0.914	1.212
SSBproj/SSBcurr	1.070	0.984	1.176
USLcurrent	0.238	0.187	0.324
USLproj	0.304	0.229	0.423
USLproj/USLcurrent	1.275	1.140	1.460
P(*Bcurr>Bmin*)	100.0%		
P(*Bcurr>Bref*)	100.0%		
P(*Bref>Bmsy*)	100.0%		
P(*Bcurr>Bmsy*)	100.0%		
P(*Bproj>Bmin*)	100.0%		
P(*Bproj>Bref*)	100.0%		
P(*Bproj>Bmsy*)	100.0%		
P(*Bproj>Bcurr*)	1.3%		
P(*SSBcurr>SSBmsy*)	39.3%		
P(*SSBproj>SSBmsy*)	73.1%		
P(*USLproj>USLcurr*)	100.0%		
P(*SSBcurr<0.2SSB0*)	0.0%		
P(*SSBproj<0.2SSB0*	0.0%		
P(*SSBcurr<0.1SSB0*)	0.0%		
P(*SSBproj<0.1SSB0*)	0.0%		

5.3 Snail trail

The form of the summary plot (snail trial) developed by the Stock Assessment Methods WG was agreed in 2010 by the RLFAWG, and is shown in Figure 36. The phase space in the plot is biomass on the x-axis and fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, the location of the stock 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_y in year y as a proportion of the unfished spawning stock, SSB0. SSB0 is constant for all years of a run, but varies through the 1000 runs.

The y-axis is fishing intensity in year y as a proportion of the fishing intensity (*Fmsy*) that would have given *MSY* 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 Fs for two seasons) that gave *MSY* is *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* (the spawning stock biomass associated with *MSY*) as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2010. 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.

This figure suggested that *SSB* has been above *SSBmsy* for most of the history of the stock.

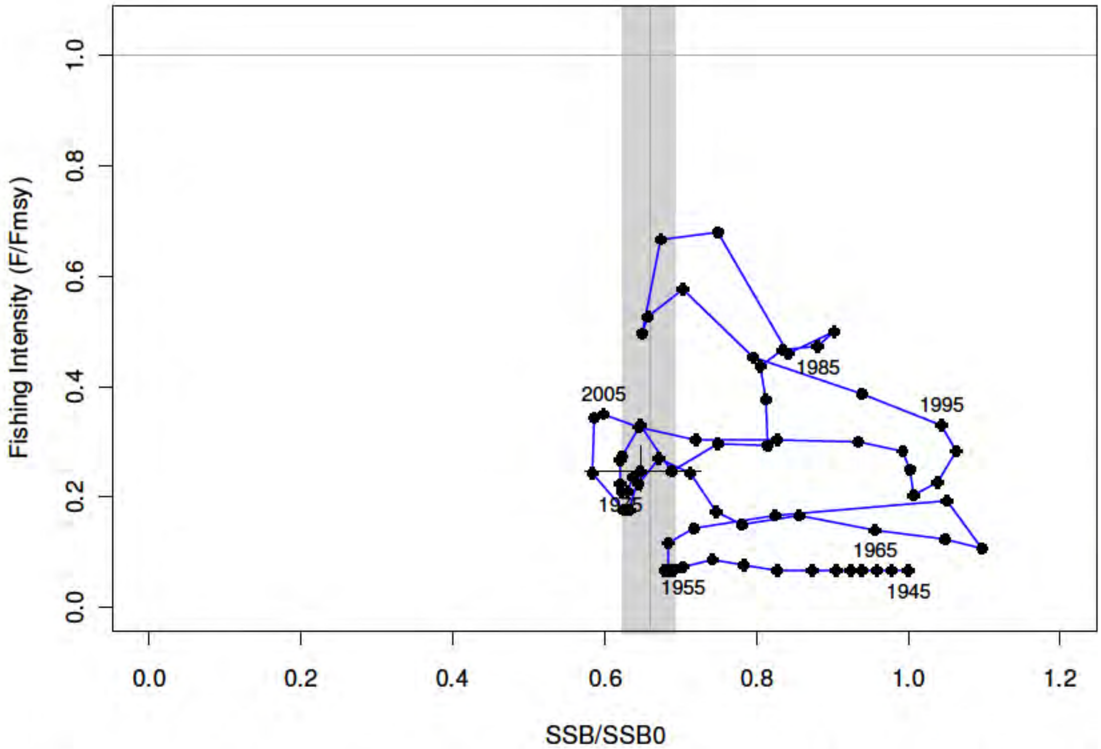

Figure 36: "Snail trail" that summarises the *SSB* history of the CRA 4 stock. The x-axis is spawning stock biomass *SSB* in year *y* as a proportion of the unfished spawning stock *SSB0*. *SSB0* is constant for all years of a run, but varies through the 1000 runs. The y-axis is fishing intensity in year *y* as a proportion of the fishing intensity (*Fmsy*) that would have given *MSY* 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 *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gives *MSY* is *Fmsy* and the multiplier is *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* (the spawning stock biomass associated with *MSY*) as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2010. 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.

5.4 Summary of the base case assessment

The current vulnerable stock is well above (roughly 2.0 to 2.5 times) *Bmsy* and *Bmin* and well above *Bref* by a lesser margin (1.9 to 2.5 times). The stock is projected to decline in the short term with high certainty, by 4–12%, but will remain above all reference levels with high certainty.

Bmsy is low. In 78% of runs it is less than *Bmin*; the associated CPUE is near 0.30. The median of *Bref/Bmsy* is 1.36.

The current *SSB* is near *SSBmsy* and near 65% *SSB0*. A large part of the *SSB* is below the MLS and is thus unaffected by the SL fishery. *SSB* is projected to increase over the short term.

5.5 McMC sensitivity trials

Several trials were agreed by the RLFAWG:

- "loVuln": a trial based on *base1*, with the alternative pattern of sex/seasonal vulnerabilities that gave very low vulnerabilities for immature females;
- "nopoo": a trial that was not fitted to the puerulus data, which estimated the final *Rdev* in 2007 and in projections re-sampled *Rdevs* from 1998–2007, this trial represents the form the assessment would have taken had the puerulus data been unavailable or had not been used;
- "poolag3": a trial fitted to the puerulus data with lag 3 years (lag was 1 year in the final base case);
- "fixed *M*": a trial with *M* fixed to 0.16;
- "hiLFwt": a trial with the weight for the LF data set to 21;
- "hiRecCat": a trial in which the recreational catch was doubled compared with the final base case vector.

Differences in the MPD estimates from these six sensitivity trials are shown in Table 11. In some trials it was necessary to adjust the LF weight slightly to obtain pdH. The low *M* and high LF weight trials showed the most difference from the base case.

Table 11: Comparison of MPDs from the McMC sensitivity trials.

	Final base	loVuln	nopoo	poolag3	fixed*M*	hiLFwt	hiRecCat
LFs-weight	3.15	3.15	3.10	3.30	3.15	21.00	3.10
LFs-sdnr	1.084	0.970	1.054	0.788	1.519	2.537	1.040
LFs-MAR	0.133	0.123	0.130	0.144	0.127	0.319	0.134
LFs-LL	156.8	146.6	151.1	165.6	155.0	921.9	154.3
Tags-weight	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Tags-sdnr	1.251	1.255	1.259	1.228	1.255	1.200	1.251
Tags-MAR	0.666	0.668	0.668	0.644	0.664	0.636	0.665
Tags-LL	3552.1	3552.7	3550.5	3549.0	3562.4	3567.7	3552.3
CPUE-weight	4.00	4.00	4.00	4.00	4.00	4.00	4.00
CPUE-sdnr	1.379	1.394	1.195	1.412	1.470	1.567	1.393
CPUE-MAR	0.995	1.114	0.699	0.955	1.052	0.942	0.987
CPUE-LL	-67.7	-66.4	-82.8	-64.7	-59.4	-50.0	-66.4
CR-weight	4.00	4.00	4.00	4.00	4.00	4.00	4.00
CR-sdnr	0.723	0.790	0.718	0.733	1.058	0.767	0.761
CR-MAR	0.655	0.644	0.537	0.589	0.760	0.572	0.693
CR-LL	31.3	31.8	31.2	31.3	34.5	31.6	31.6
Poo-Lswitch	1	1	0	1	1	1	1
Poo-weight	1.00	1.00	n.a	1.00	1.00	1.00	1.00
Poo-sdnr	1.032	0.994	n.a	1.047	1.372	1.377	1.022
Poo-MAR	0.532	0.615	na	0.718	0.830	0.860	0.526
Poo-LL	-20.1	-21.3	n.a	-18.1	-6.7	-6.6	-20.4
Priors	-38.8	-38.6	-36.4	-24.9	-28.8	-33.1	-39.0
function value	3613.6	3604.9	3613.6	3638.3	3657.1	4431.4	3612.3
ln(*R0*)	15.436	15.449	15.196	14.974	14.468	15.076	15.340
M	0.326	0.323	0.303	0.326	0.16*	0.276	0.301
ln(*qCPUE*)	-6.575	-6.556	-6.592	-6.443	-6.233	-6.538	-6.636
ln(*qCR*)	-2.439	-2.652	-2.484	-2.282	-2.312	-2.524	-2.519
ln(*qPoo*)	-15.394	-15.405	na	-14.929	-14.491	-15.046	-15.309
*mat50_*	39.17	63.04	38.46	30.00	49.42	39.87	39.30
mat95add	13.93	13.34	13.87	13.93	16.11	12.48	13.95
GalphaM	3.140	3.123	3.281	3.480	3.184	3.195	3.144

	Final base	loVuln	nopoo	poolag3	fixed*M*	hiLFwt	hiRecCat
GbetaM	2.045	2.079	1.874	1.712	1.874	2.547	2.039
GdiffM	0.651	0.666	0.571	0.492	0.589	0.797	0.649
GshapeM	5.373	5.284	5.711	7.312	5.306	6.184	5.388
GrowthCVM	0.416	0.416	0.395	0.416	0.409	0.416	0.416
GalphaF	3.082	3.079	3.129	3.348	2.060	2.696	3.113
GbetaF	1.222	1.202	1.202	1.173	1.339	1.578	1.225
GdiffF	0.396	0.391	0.384	0.350	0.650	0.585	0.393
GshapeF	5.627	5.456	5.723	6.305	4.698	6.246	5.612
GrowthCVF	0.629	0.615	0.637	0.669	0.772	0.785	0.626
vuln1	0.733	0.733	0.779	0.646	0.639	0.857	0.768
vuln2	0.513	0.534	0.556	0.477	0.515	0.603	0.531
vuln3	0.755	0.012	0.759	0.753	0.812	0.773	0.750
vuln4	1*	0.741	1*	1*	1*	1*	1*
VL1M	7.07	7.02	7.73	8.47	8.34	6.35	7.13
SelectMax1M	57.75	57.77	58.21	56.85	60.05	55.73	57.73
VL1F	15.57	8.55	16.09	16.98	12.21	12.77	15.83
SelectMax1F	80.00	50.79	80.00	80.00	75.29	72.89	80.00
VL2M	5.11	5.12	5.16	5.73	5.37	5.15	5.15
SelectMax2M	56.47	56.62	56.20	56.11	56.31	56.46	56.43
VL2F	8.01	11.97	8.05	8.73	8.39	7.92	8.03
SelectMax2F	68.80	66.11	68.30	69.30	69.42	68.14	68.65
Rdev_prior	-40.4	-39.7	-38.5	-39.5	-26.2	-38.6	-40.1
M_prior	2.5	2.4	2.0	2.5	-1.4	1.3	1.9
Growth_priors	-0.3	-0.8	0.7	12.7	-1.0	4.5	-0.3
Sel_prior	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other_priors	-0.5	-0.5	-0.5	-0.5	-0.3	-0.4	-0.5
Bcurr/Bref	1.724	1.741	1.798	1.711	1.466	1.989	1.725
Bref	464.2	448.1	483.1	397.9	381.4	400.0	489.8
Bmsy	358.8	368.3	397.1	324.3	467.2	420.9	395.8
MSY	674.0	656.7	659.8	655.1	519.8	613.0	703.7
Fmult	3.940	3.650	3.740	3.680	1.380	2.890	3.370
Male_yrs to MLS	4.5	4.5	4.0	3.0	4.0	4.0	4.5
Female_yrs to MLS	6.5	6.5	6.0	5.5	10.5	7.0	6.5

These sensitivity trials were all run for 1 million McMC simulations, saving 1000 samples. As was done for the base case McMC, *GrowthCV* was estimated in the minimisation and then fixed at the estimated MPD values for the McMC. The posterior distributions of parameter estimates are compared in Table 12; indicators are compared in Table 13. The trials causing the least change in indicators relative to the base case were the high recreational catch and no puerulus trials. The fixed *M* trial had the greatest effect, with much smaller biomass indicators, much higher CPUE at *Bmsy* and *Bcurr* above reference levels with smaller margins. All trials except the high recreational catch showed substantial variation in the comparison of current and projected *SSB* with *SSBmsy*.

Table 12: Medians of the posterior distributions for estimated parameters in the McMC sensitivity trials.

Value	Final base	loVuln	nopoo	poolag3	fixed*M*	hiLFwt	hiRecCat
function value	3 658	3 651	3 659	3 682	3 697	4 478	3 657
ln(*R0*)	15.41	15.39	15.27	14.96	14.47	15.04	15.36
M	0.322	0.315	0.319	0.325	0.160	0.275	0.303
ln(*qCPUE*)	-6.664	-6.640	-6.683	-6.537	-6.433	-6.555	-6.715
ln(*qCR*)	-2.738	-2.926	-2.699	-2.643	-2.641	-2.789	-2.815
ln(*qpuerulus*)	-15.37	-15.35	na	-14.92	-14.47	-15.02	-15.32
mat50	37.7	62.7	37.6	30.5	48.6	39.3	37.6
mat95add	14.0	13.9	13.9	13.9	16.1	13.1	14.2
Galpha_M	3.13	3.12	3.21	3.46	3.20	3.18	3.13
GBeta_M	1.98	2.00	1.87	1.69	1.73	2.52	1.98
Gdiff_M	0.63	0.64	0.58	0.49	0.54	0.79	0.63
Gshape_M	5.47	5.45	5.77	7.43	5.44	6.52	5.45
Galpha_F	3.11	3.11	3.12	3.38	2.15	2.73	3.14
GBeta_F	1.20	1.16	1.20	1.14	1.24	1.56	1.21
Gdiff_F	0.39	0.38	0.38	0.34	0.57	0.57	0.38
Gshape_F	5.66	5.53	5.70	6.34	4.78	6.25	5.62
vuln1	0.75	0.76	0.71	0.67	0.75	0.85	0.77
vuln2	0.52	0.55	0.51	0.49	0.59	0.59	0.53
vuln3	0.76	0.01	0.75	0.76	0.82	0.77	0.75
vuln4	1.00	0.75	1.00	1.00	1.00	1.00	1.00
VL1_M	7.4	7.4	7.4	8.4	8.7	6.5	7.4
SelectMax1_M	57.9	58.0	57.4	56.2	60.3	55.8	57.7
VL1_F	15.8	21.0	16.0	17.4	12.9	13.0	16.0
SelectMax1_F	79.9	55.7	79.9	79.9	75.6	73.1	79.9
VL2_M	5.1	5.1	5.1	5.8	5.4	5.2	5.2
SelectMax2_M	56.3	56.4	55.9	55.9	56.1	56.4	56.3
VL2_F	8.0	12.3	8.0	8.8	8.3	7.9	8.0
SelectMax2_F	68.5	66.6	68.4	68.9	68.5	68.1	68.4

Table 13: Medians of indicators from posterior distributions for agreed indicators in the McMC sensitivity trials and (lower portion) the probability that propositions were true.

	Final base	loVuln	nopoo	poolag3	fixed*M*	hiLFwt	hiRecCat
Bmin	407	398	416	355	365	321	423
Bcurr	862	844	941	742	674	805	898
Bref	514	495	521	438	477	411	536
Bproj	751	727	770	607	571	663	831
Bmsy	377	385	374	343	547	416	408
MSY	680	655	676	662	532	610	715
Fmult	4.05	3.76	4.44	3.81	1.50	2.96	3.57
SSBcurr	2 615	809	2 496	1 826	1 513	1 999	2 654
SSBproj	2 796	829	2 457	1 690	1 576	2 147	2 864
SSBmsy	2 646	652	2 387	1 757	1 739	2 143	2 675
CPUEcurrent	0.91	0.91	1.01	0.91	0.91	0.95	0.91
CPUEproj	0.77	0.75	0.78	0.69	0.74	0.73	0.83
CPUEmsy	0.29	0.31	0.29	0.30	0.68	0.38	0.31
Bcurr/Bmin	2.12	2.11	2.27	2.08	1.87	2.52	2.11

	Final base	loVuln	nopoo	poolag3	fixed*M*	hiLFwt	hiRecCat
Bcurr/Bref	1.68	1.70	1.82	1.69	1.42	1.96	1.68
Bcurr/Bmsy	2.30	2.20	2.56	2.15	1.26	1.94	2.21
Bproj/Bcurr	0.87	0.86	0.82	0.82	0.85	0.83	0.93
Bproj/Bref	1.46	1.47	1.49	1.38	1.22	1.61	1.56
Bproj/Bmsy	2.01	1.90	2.08	1.78	1.08	1.60	2.04
SSBcurr/SSB0	0.65	0.43	0.67	0.62	0.46	0.58	0.63
SSBproj/SSB0	0.69	0.44	0.65	0.57	0.48	0.62	0.68
SSBcurr/SSBmsy	0.98	1.24	1.04	1.04	0.87	0.93	0.99
SSBproj/SSBmsy	1.05	1.27	1.01	0.96	0.91	1.01	1.07
SSBproj/SSBcurr	1.07	1.03	0.96	0.92	1.04	1.08	1.08
USLcurrent	0.24	0.24	0.21	0.27	0.31	0.25	0.23
USLproj	0.30	0.31	0.30	0.38	0.40	0.34	0.25
USLproj/USLcurrent	1.28	1.29	1.38	1.39	1.29	1.36	1.07
P(*Bcurr>Bmin*)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(*Bcurr>Bref*)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(*Bcurr>Bmsy*)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(*Bproj>Bmin*)	1.00	1.00	0.99	1.00	1.00	1.00	1.00
P(*Bproj>Bref*)	1.00	1.00	0.91	1.00	0.94	1.00	1.00
P(*Bproj>Bmsy*)	1.00	1.00	0.99	1.00	0.69	1.00	1.00
P(*Bproj>Bcurr*)	0.01	0.02	0.18	0.01	0.02	0.01	0.12
P(*SSBcurr>SSBmsy*)	0.39	1.00	0.64	0.71	0.01	0.13	0.45
P(*SSBproj>SSBmsy*)	0.73	1.00	0.52	0.35	0.10	0.53	0.79
P(*USLproj>USLcurr*)	1.00	1.00	0.91	1.00	1.00	1.00	0.83
P(*SSBcurr<0.2SSB0*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(*SSBproj<0.2SSB0*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(*SSBcurr<0.1SSB0*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(*SSBproj<0.1SSB0*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Based on the differences between *base1* and *base2* in terms of mature females, we expected that the snail trail from the loVuln sensitivity trial (Figure 37), and possibly the fixed*M* trial (Figure 38), would show patterns of *SSB* behaviour different from the base case (Figure 36). Whereas the base case has current *SSB* near *SSBmsy*, the fixedM trial has *SSB* less than *SSBmsy* and the loVuln trial greater than *SSBmsy*. In the fixed*M* trial, the fishing intensity exceeded *Fmsy* by a factor of nearly 2 in the 1980s.

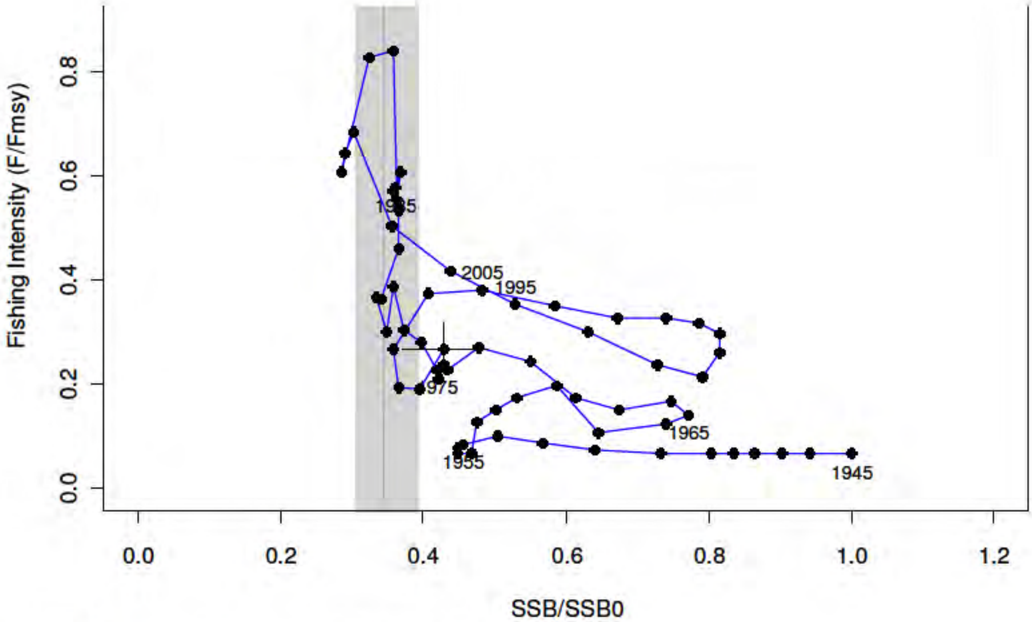

Figure 37: Snail trail from the loVuln sensitivity trial.

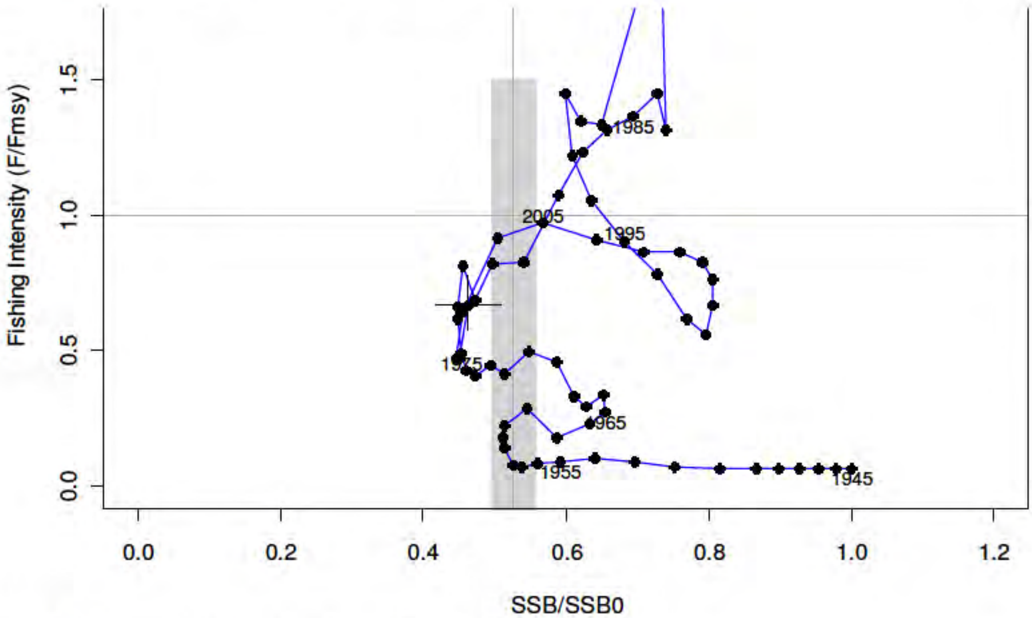

Figure 38: Snail trail from the fixed*M* sensitivity trial.

6. Management procedure evaluations (MPEs)

6.1 Projections for MPEs

The MPE projections were made using a projection version of final base case operating model and the joint posterior distribution from the final base case McMC.

Projections were made for 20 years, to 2031, with the harvest control rules first affecting the TACC in 2012. Projected recruitment was based on the mean estimated recruitment for 2002–2011. The TACC was set by the harvest control rule being tested, driven by the model's predicted offset-year CPUE, while recreational catch was calculated from the model's recreational exploitation rate calculated for 1979–2010. The illegal catch was held constant at 40 t and the customary catch at 20 t.

6.1.1 AW commercial catch proportion

The TACC determined by the harvest control rule was split into the two seasons. The AW catch proportion for 2011 was based on 2010. In subsequent years, the proportion was based on the historical relation between observed AW proportion and AW CPUE (Eq. 1):

Eq. 1 $${}^{AW}\hat{P}_y = \delta\,{}^{AW}I_y + \nu$$

where ${}^{AW}\hat{P}_y$ is the estimated AW catch proportion fishing year y, ${}^{AW}I_y$ is AW CPUE in year y and δ and ν are parameters of the regression model.

We examined the relation between standardised AW CPUE for CRA 4 and the proportion of the commercial catch taken in the AW season using all observations since 1993 (after size limit and escape gap regulation changes) (Table 14, Figure 39). As a result of RLFAWG discussion arising from obvious trends in the residuals, we also examined the relation using only those values since 2003 (Table 14, Figure 40). The AW catch proportions from the relations were truncated at 5% and 95%.

The results of this short sensitivity trial in terms of model projections (Table 15, Figure 41 and Figure 42) indicated that there was no sensitivity to which procedure was used, and the MPEs used the original procedure.

Table 14: Parameter values for the regression of the AW catch commercial proportion against standardised AW CPUE in the base.

Coefficient	Base case	Sensitivity
Slope	0.781	0.783
Intercept	-0.0567	-0.178
R^2	0.719	0.926

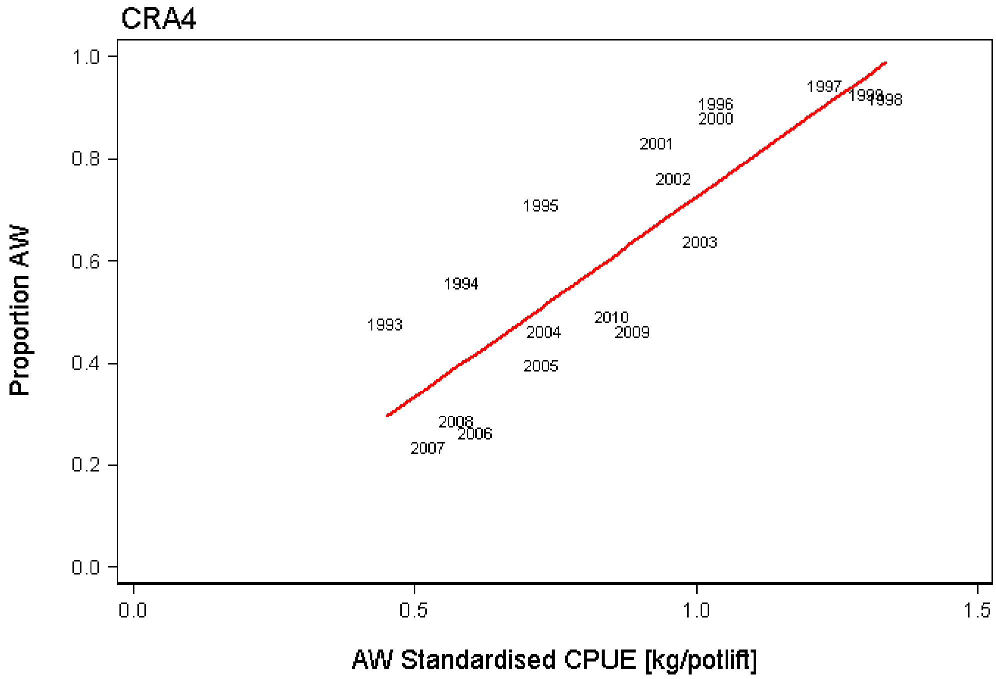

Figure 39: Plot of the relation between AW standardised CPUE and the proportion of commercial catch taken in AW of the same year using all values from 1993.

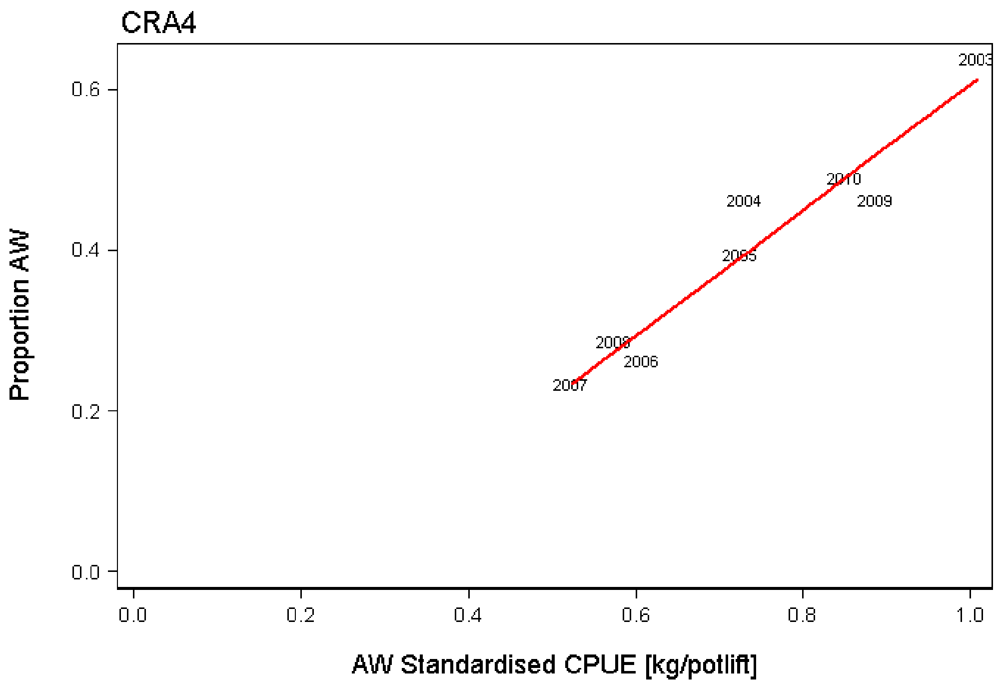

Figure 40: Plot of the relation between AW standardised CPUE and the proportion of commercial catch taken in AW of the same year using all values from 2003.

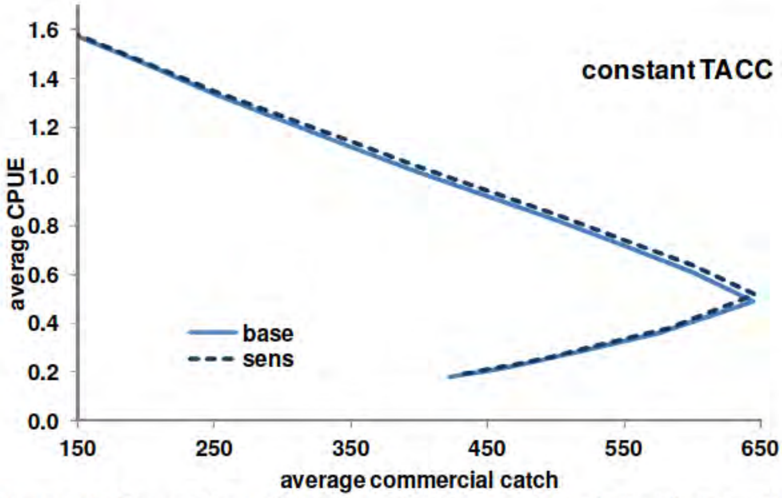

Figure 41: Comparison of the abundance vs. catch relation between the base case and sensitivity trial for simple fixed-TACC rules.

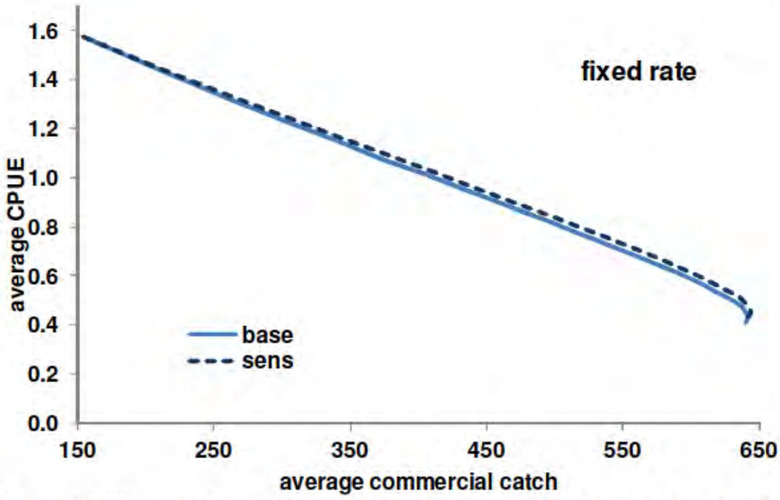

Figure 42: Comparison of the abundance vs. catch relation between the base case and sensitivity trial for simple fixed-rate rules.

Table 15: The average (across all rules) percentage change in mean catch and mean abundance for the same simple rules between the base case and the alternative AW catch proportion calculation.

	Mean catch	Mean abundance
Fixed TACC	0.5%	3.1%
Constant rate	1.0%	1.1%

6.1.2 Offset-year CPUE

The model must also predict offset year CPUE (1 October through 30 September) for use in the harvest control rule. The model predicted AW and SS CPUE; these needed to be combined in a realistic way to obtain projected offset-year CPUE.

The predictive equation was based on a regression of offset year CPUE against the mean of AW CPUE in the same fishing year and SS CPUE in the previous fishing year (Eq. 2):

Eq. 2 $$^{o}\hat{I}_y = \delta \frac{\left({}^{AW}I_y + {}^{SS}I_{y-1}\right)}{2} + \nu$$

where $^{o}\hat{I}_y$ is the predicted offset-year CPUE in the fishing year that includes the AW, $^{AW}I_y$ is the model's observed (with error) AW CPUE, $^{SS}I_{y-1}$ is the preceding SS CPUE and δ and ν are parameters of the regression model. We fitted this model to all complete offset years from 1 October 1979 to 30 September 2010 (Figure 43; Table 16). The offset year CPUE used for this analysis is documented in Appendix A. The model used CPUE observation error when projecting offset-year CPUE.

Table 16: Parameter values for the regressions of AW standardised CPUE against the proportion of the CRA 5 AW seasonal commercial catch. (R^2=0.964).

Coefficient	Values
Slope	0.8670
Intercept	0.0865

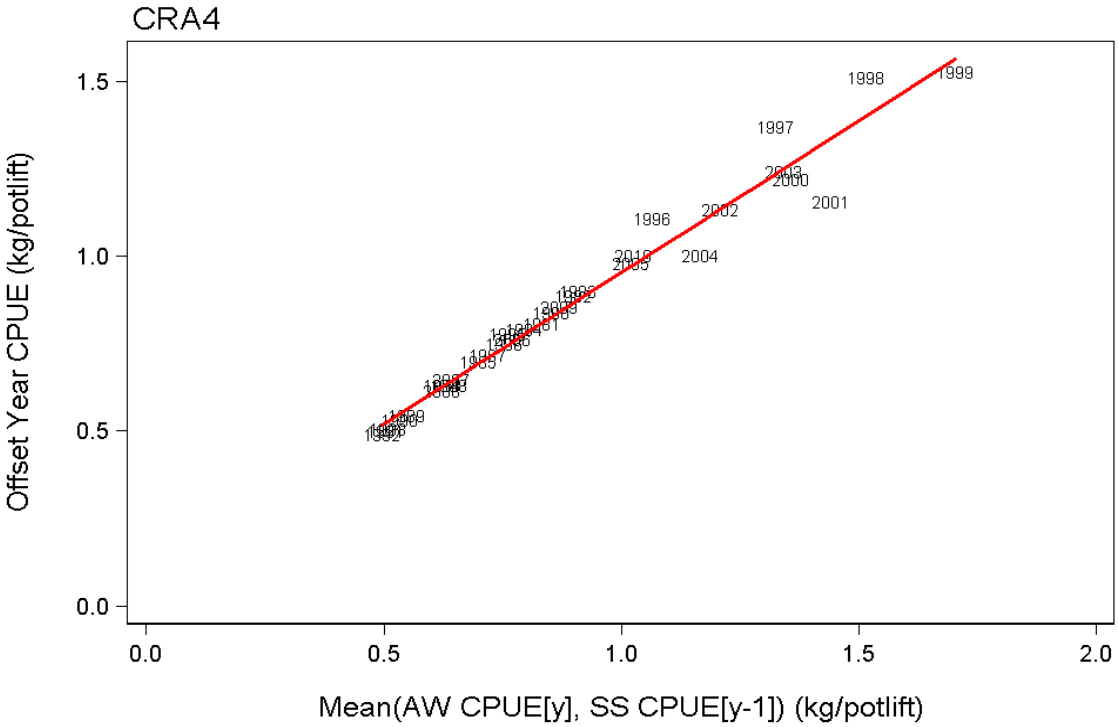

Figure 43: Plot of the relation between the mean AW and SS standardised CPUE and the offset year CPUE index.

6.2 Productivity of the operating model

6.2.1 Base case

We explored the productivity of the operating model by making runs with fixed-TACCs and fixed-rate harvest control rules; the latter simply set TACC as some linear function of CPUE. Fixed TACCs were varied from 100 to 1000 t and the straight-line rules were varied to give from 100 to 2000 t when CPUE = 1.0. Results (Figure 44 and Figure 45) suggested that the maximum SL catch was 670 t, not very different from the median estimated MSY of 674 t (Table 17). They suggested that an average commercial catch of 400 t was associated with an average CPUE of 1 kg/potlift. At first blush, this relation seemed low: the mean commercial catch from 1979–2009 was 591 t and mean CPUE was 0.87 kg/pot. However, recruitment over the past decade was lower than in the past (Figure 32): recruitment in 2002–11 was 14% less than in 1979–2001.

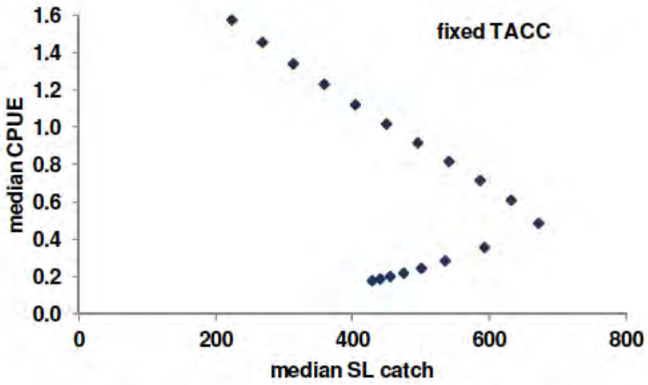

Figure 44: From a series of fixed-TACC rules, the median of mean CPUE during a run plotted against the sum of median mean commercial catch and median of mean recreational catch.

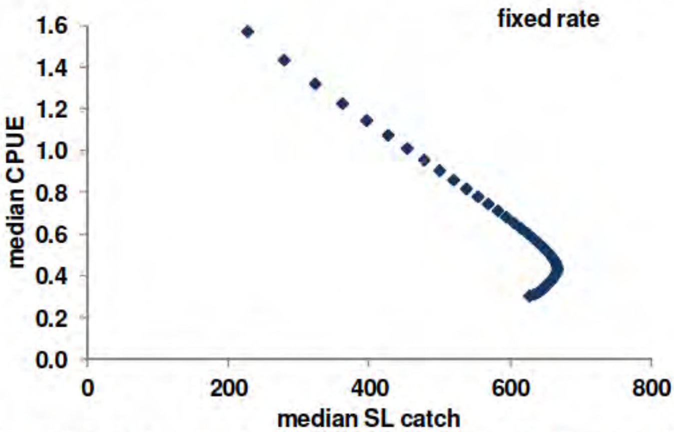

Figure 45: From a series of fixed-rate rules, the median of mean CPUE during a run plotted against the sum of median mean commercial catch and median of mean recreational catch.

6.2.2 McMC sensitivity trials

The McMC sensitivity models differed in their productivities: some indicators are given in Table 17. The fixed *M* trial had the lowest productivity in terms of *MSY*; the base case was second highest, after the hiRecCat trial; similarly with the highest safe commercial catch. The CPUE at *MSY* was near 0.4–0.5 kg/potlift for all models, but CPUE associated with 500 t average catch (unsafe in some models) varied from 0.275 in the base case to 0.828 in hiRecCat. The commercial catch associated with a CPUE of 1.0 was similar, near 410 t, except for the nopoo and poolag3 trials. Commercial catch at a CPUE of 1.5 varied from less than 100 t for poolag3 to 334 t for fixedM. The rules are compared in Figure 46.

When the no-puerulus and puerulus lag 3 trials are omitted, all the models show a convergence at approximately 400–500 t commercial catch. The no-puerulus and puerulus lag 3 trials show lower CPUE for a given average catch level, or a lower catch for a given average CPUE level. This suggests that, at least when considering the model productivity in MPEs, the main uncertainty among the models is puerulus, and the issues around *M*, LF weighting, immature female vulnerability and recreational catch are not substantial.

Table 17: Comparing some productivity indicators from exploratory runs (constant TACC and constant rate rules) for the McMC base case and McMC sensitivity trials. The columns are: maximum commercial catch, maximum of commercial plus recreational medians, the maximum commercial catch with fewer than 5% of years less than *Bref*, the average CPUE associated with maximum commercial catch, interpolated average CPUE associated with commercial catch of 500 t, interpolated average commercial catch associated with CPUE of 1.0 kg/potlift and 1.5 kg/potlift.

	Max. comm.	Max. SL	Max. safe comm.	CPUE at max. comm.	CPUE at comm.=500	Comm. at CPUE=1.0	Comm. at CPUE=1.5
base	645.1	671.7	514.2	0.490	0.275	410.4	181.8
loVuln	611.1	637.9	511.2	0.449	0.803	415.7	205.3
nopoo	600.8	623.1	407.5	0.406	0.701	358.7	119.3
poolag3	548.6	571.7	390.0	0.401	0.587	316.7	<100
fixedM	502.3	533.1	450.7	0.507	0.567	430.6	334.2
hiLFwt	560.0	585.7	504.0	0.444	0.292	407.3	244.9
hiRecCat	657.6	706.4	536.7	0.416	0.828	415.5	173.6

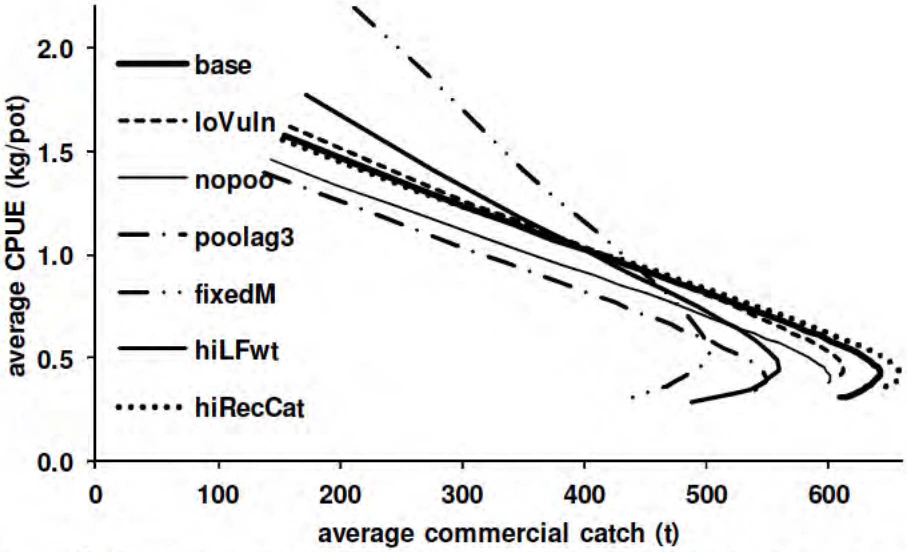

Figure 46: Average commercial CPUE vs. average commercial catch in a series of fixed-rate rules with different operating models.

6.3 Harvest control rule family

MPEs were made with members of the same generalised harvest control rule family used in 2010 for CRA 5 MPEs (Haist et al. 2011).

For this rule family, the input is standardised CPUE in the preceding offset year and the output is a TACC (Figure 47). An initial ascending or rebuilding phase rises from zero TACC (not necessarily at zero CPUE) to an initial plateau. At the end of the initial plateau there is a stepped increase to a new plateau; the second plateau or step has a fixed width, with a proportional increase step at its end, and this pattern is repeated indefinitely as CPUE increases. The parts of the rule are thus the rebuilding phase, the initial plateau and the steps. In special cases any of these parts can be eliminated.

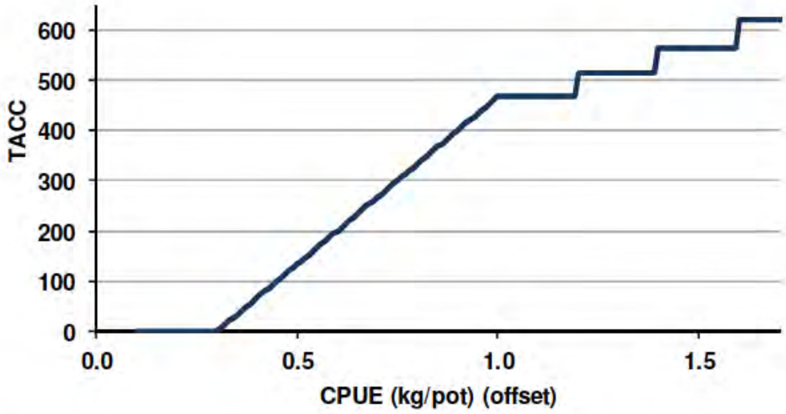

Figure 47: A TACC step rule.

Parameters of this generalised rule are:

par2 the CPUE at which the TACC becomes zero
par3 the CPUE at which the first plateau begins (plateau left)
par4 the CPUE at which the first plateau ends (plateau right)
par5 the width of subsequent CPUE plateaux
par6 the TACC on the first plateau
par7 the proportion by which TACC increases at a step
par8 maximum allowed increase (a proportion) when TACC is to the left of the main plateau
par9 and *par 10* are not used.

The rule is described by:

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

$$TACC_{y+1} = \frac{par6}{par3 - par2}\left(I_y - par2\right) \qquad \text{for } par2 < I_y \le par3$$

$$TACC_{y+1} = par6 \qquad \text{for } par3 < I_y \le par4$$

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

where $TACC_{y+1}$ is the TACC (t) in year *y*+1 and I_y is offset-year CPUE (kg/potlift) in year *y*. The rule has no latent year and no thresholds for minimum and maximum change, except that maximum increase is restricted when on the rebuilding slope.

7.4 Indicators for MPEs

Indicators, initially specified by MFish, were discussed and agreed by the RLFAWG. Biomass indicators except for *SSB* were calculated as pre-season AW vulnerable biomass.

The list of output indicators was:

- mean biomass during the 20-year run, scaled as a proportion of *Bref;*
- terminal biomass, scaled as a proportion of *Bref;*
- minimum commercial catch during the run;
- mean commercial catch during the run;
- the mean commercial catch during the first five years of the run;

- minimum recreational catch during the run;
- mean recreational catch during the run;
- minimum observed offset-year CPUE during the run;
- mean observed offset-year CPUE during the run;
- average annual variation in TACC during the run;
- projected biomass as a proportion of *Bmsy;*
- CPUE in AW of the last projected year;
- the proportion of years in which biomass was less than *Bref;*
- the proportion of years in which biomass was less than *Bmin;*
- the proportion of years in which biomass was less than *Bmsy;*
- the proportion of years in which TACC changed;
- the proportion of years in which *SSB* was less than 20% *SSB0;*
- the proportion of years in which *SSB* was less than 10% *SSB0;*
- the proportion of years in which CPUE was greater than 0.6, 0.7, 0.8, 0.9, 1.0, 1.1 and 1.2 kg/potlift.

The average annual variation in TACC was calculated as:

$$AAVH = \frac{\sum_{y=2011}^{y=2030} 100 \frac{\left|TACC_y - TACC_{y-1}\right|}{0.5\left(TACC_y + TACC_{y-1}\right)}}{20}$$

Indicators were calculated for each run. Except for indicators defined as “the proportion of years in which...”, indicators were summarised for the whole set of 1000 runs by the 5th and 95th quantiles and medians of their posterior distributions.

7.5 Productivity of the operating model with generalised rules

Section 6.2 shows the results of exploratory trials with simple constant-TACC and constant-rate rules. The present short section illustrates the trade-offs from a broader range of rule types. A variety of rule members were explored, and all these rules, including those from the section above, are illustrated here.

There was a strong relation between abundance and CPUE, which in the area of interest (near average CPUE of 1.0) was essentially a straight line with little variation (Figure 48). Because the model’s recreational catch is proportional to abundance, and thus proportional to CPUE, the relation between recreational catch and commercial catch is also a straight line with little variation (Figure 49). In the runs we explored, there were few years with biomass less than *Bref* except with the simple exploratory rules (Figure 50). There was substantial variability in average annual catch variation, which depended on the specific shape of the various plateau rules (Figure 51).

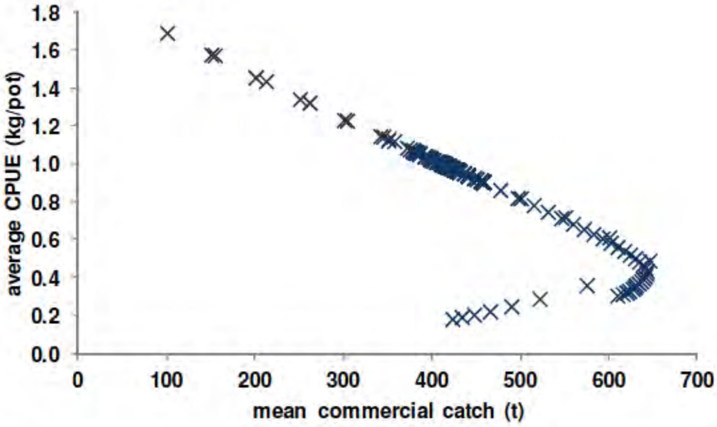

Figure 48: For roughly 250 rules, the relation between mean CPUE and mean commercial catch in base case MPEs.

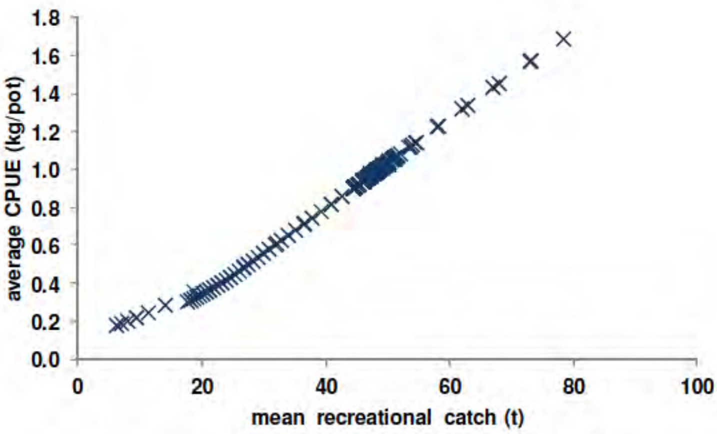

Figure 49: For roughly 250 rules, the relation between mean CPUE and mean recreational catch in base case MPEs.

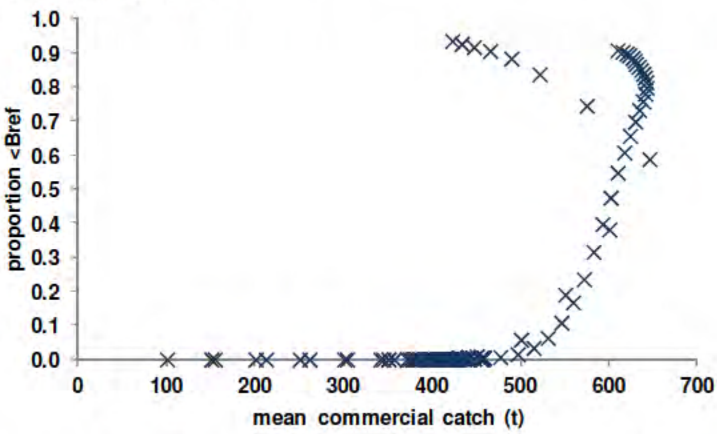

Figure 50: For roughly 250 rules, the relation between the proportion of years less than *Bref* and the mean commercial catch in base case MPEs.

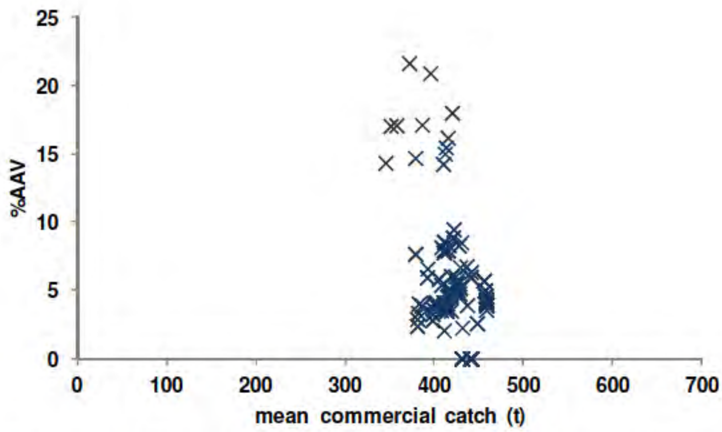

Figure 51: For roughly 200 rules (the constant-TACC and constant-rate exploratory rules were removed), the relation between AAV and the mean commercial catch in base case MPEs.

7.6 Management procedure development and evaluation

7.6.1 Base case

In developing a final set of management procedure candidates, we were guided by the productivity considerations described above and a meeting[2] at which all three stakeholder groups indicated a desire for "high abundance", "high catch rates" or the equivalent. The current abundance available when we did this work, estimated using the standardised annual CPUE in the year to 31 March 2011, was 1.03 kg/potlift (Starr 2011)[3]. The operating model suggested that the average commercial catch associated with an average CPUE of 1.0 kg/potlift was 400 t. Higher average catches would be associated with lower CPUE: this is obviously not very desirable based on input from stakeholders. Higher CPUE would be associated with lower average catches.

We sought a set of five or six rules that would illustrate the trade-offs available. We developed four rules that would leave the existing TACC (467 t) in place if CPUE remained above 1.0, and developed two rules that would reduce TACC if CPUE remained near 1.0. These six rules were refined from a larger exploratory set of about 200 rules, independently developed among us, so in the full set of 200 there may be duplicates.

The commercial stakeholders from CRA 4 requested a variant of one of the rules on 13 October, and we added this to the set of rules, making seven "final candidates".

This set of rules varied in:

- whether the rule delivered an immediate TACC reduction;
- where the estimated current situation was with respect to the rebuild slope;
- how wide the plateaux were;
- how aggressive the slope was above the first plateau.

Rule results differed with respect to the indicators, in particular where the rules were on the balance between mean catch/mean CPUE, and in how they responded to the robustness trials. All the rules had a 25% increase limit when below the first plateau. They were not evaluated

[2] convened by MFish in Masterton, 30 September 2011
[3] In early November, standardised offset CPUE for the year ending 30 September 2011 was calculated as 1.19 kg/potlift (P.J. Starr, unpublished data)

with a minimum change rule, but that could be imposed without changing the results of the rule substantially.

All the rules were safe. Two of them reached just over 5% of years below *Bref* in the fixed*M* or poolag3 robustness trials; there were no other problems.

Parameters for the seven rules are shown in Table 18. The rules are illustrated in Figure 52 to Figure 57.

Table 18: Parameters for the seven final rule candidates.

Rule	TACC zero Par(2)	Plateau left Par(3)	Plateau right Par(4)	Step width Par(5)	Plateau height Par(6)	Step increase Par(7)	Max change Par(8)
2011-28	0.5	0.8	1.3	0.1	467	0.07	0.25
2011-29	0.3	1	1.2	0.2	467	0.1	0.25
2011-30	0.3	0.8	1	0.2	445	0.05	0.25
2011-31	0.3	0.8	1	0.25	400	0.1675	0.25
2011-32	0.3	1	1.1	0.1	400	0.05	0.25
2011-33	0.3	0.9	1.1	0.1	400	0.05	0.25
2011-28a	0.5	0.9	1.3	0.1	467	0.07	0.25

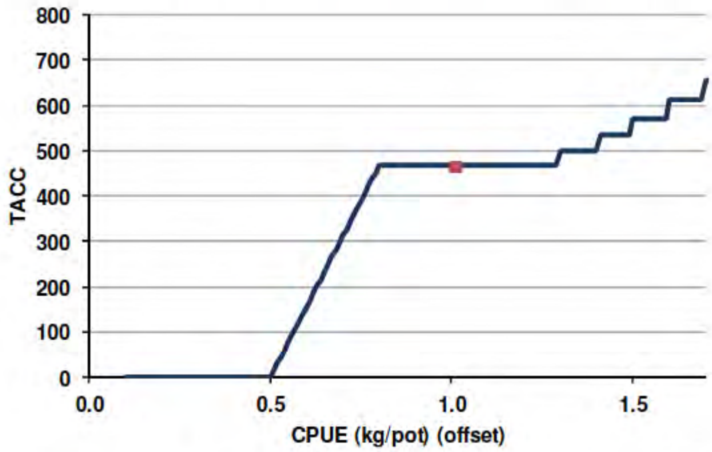

Figure 52: Rule 28; the red dot shows the current TACC and CPUE just over 1.0.

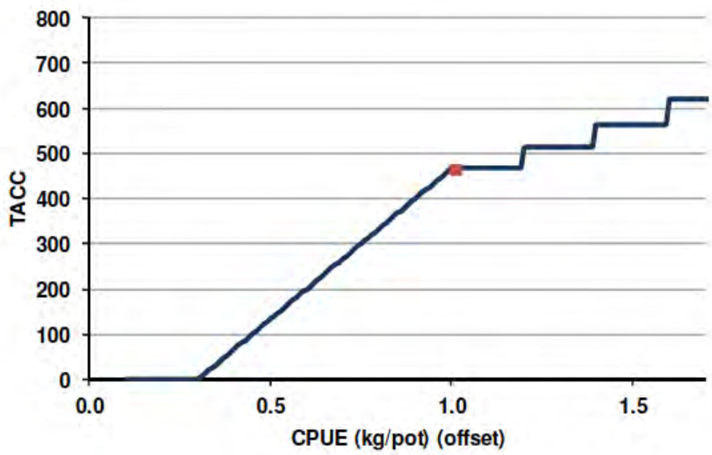

Figure 53: Rule 29; the red dot shows the current TACC and CPUE just over 1.0.

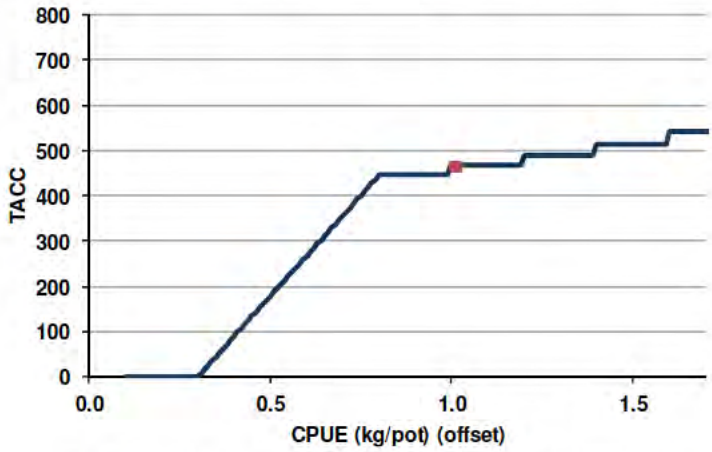

Figure 54: Rule 30; the red dot shows the current TACC and CPUE just over 1.0.

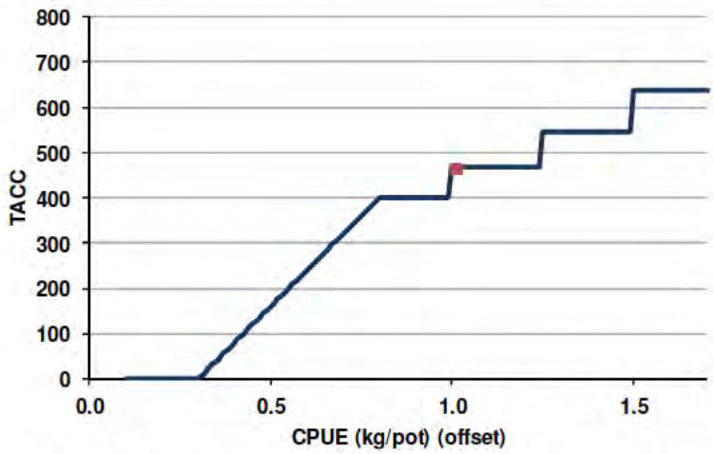

Figure 55: Rule 31; the red dot shows the current TACC and CPUE just over 1.0.

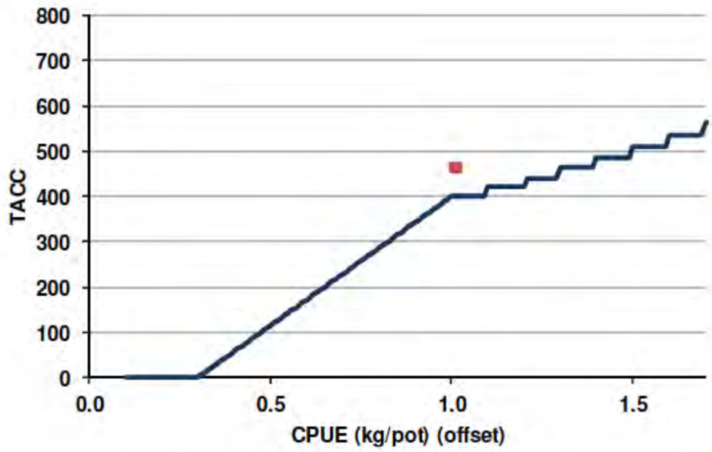

Figure 56: Rule 32; the red dot shows the current TACC and CPUE just over 1.0.

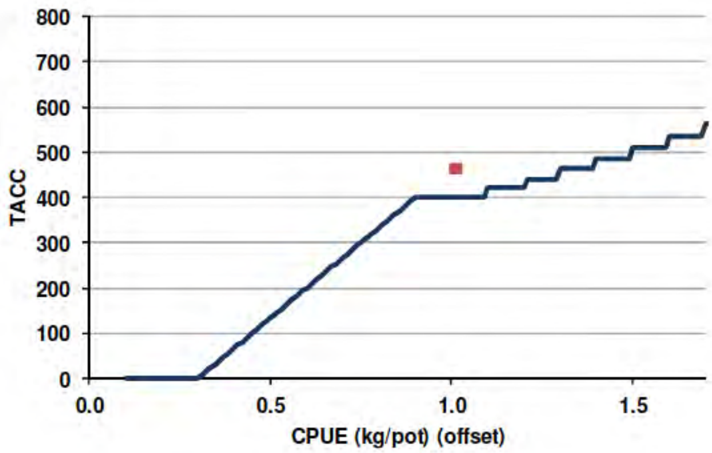

Figure 57: Rule 33; the red dot shows the current TACC and CPUE just over 1.0.

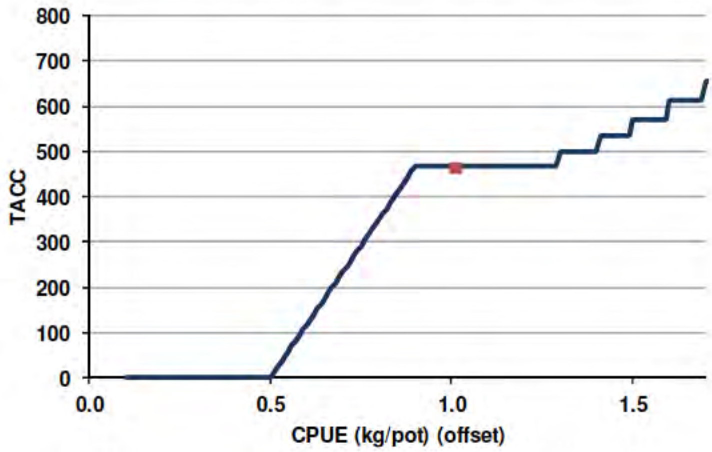

Figure 58: Rule 28a; the red dot shows the current TACC and CPUE just over 1.0.

The base case performance of the rules with respect to five main indicators is shown in Table 19: Mean commercial catch varied from 392–457 t and CPUE from 0.90–1.04 kg/potlift.

Table 19: Performance of the seven rules in base case MPEs.

Comments	No.	Model	Mean catch	Mean CPUE	Mean Rec.	%AAV	CPUE <0.8	CPUE >1.2
Long plateau	28	base	457.3	0.904	44.3	3.6	11.8%	2.4%
Moderate rule	29	base	426.6	0.965	46.8	8.3	2.5%	3.2%
Aggressive rule	30	base	446.9	0.925	45.2	2.6	9.5%	2.7%
2-plateau rule	31	base	425.5	0.971	47.1	5.0	3.6%	3.6%
Conservative rule–narrow 400 t plateau	32	base	391.5	1.040	50.0	6.6	0.3%	10.6%
Conservative rule–wider 400 t plateau	33	base	401.1	1.019	49.1	3.8	1.1%	9.2%
Variant of rule 28	28a	base	438.7	0.939	45.7	7.6	4.8%	3.0%

Figure 59 shows the percentage of years at each CPUE level for each rule. No rule spent much time at CPUE less than 0.7 kg/potlift. The two highest-catch rules, 28 and 30, spent about 10% of their time in the 0.7 class and most of their time in 0.8 and 0.9. The two moderate rules, 29 and 31, spent little time in the 0.7 class and more of their time in the 0.9

class; the two lower-catch rules, 32 and 33, spent most time in the 0.9 and 1.0 classes, with 10% in 1.2 and above.

The full set of indicators is given in Appendix B, Table B1. Individual runs for each of the seven rules are plotted for three samples of the posterior (the same samples for each rule) in Figure 60 through Figure 68.

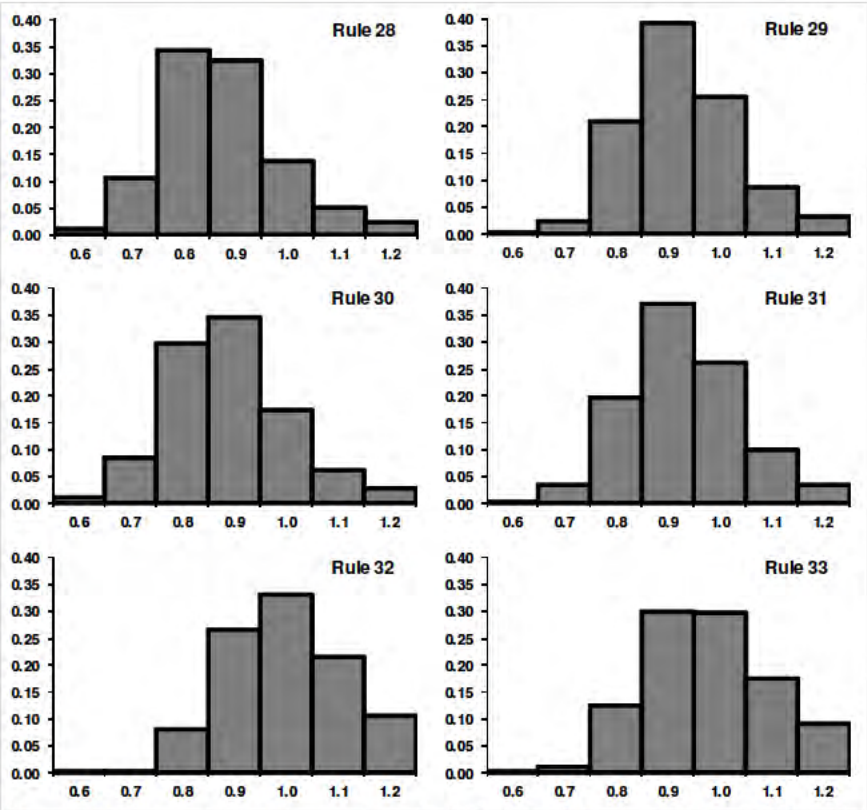

Figure 59: Proportion of years at each CPUE level for each of the initial six rules.

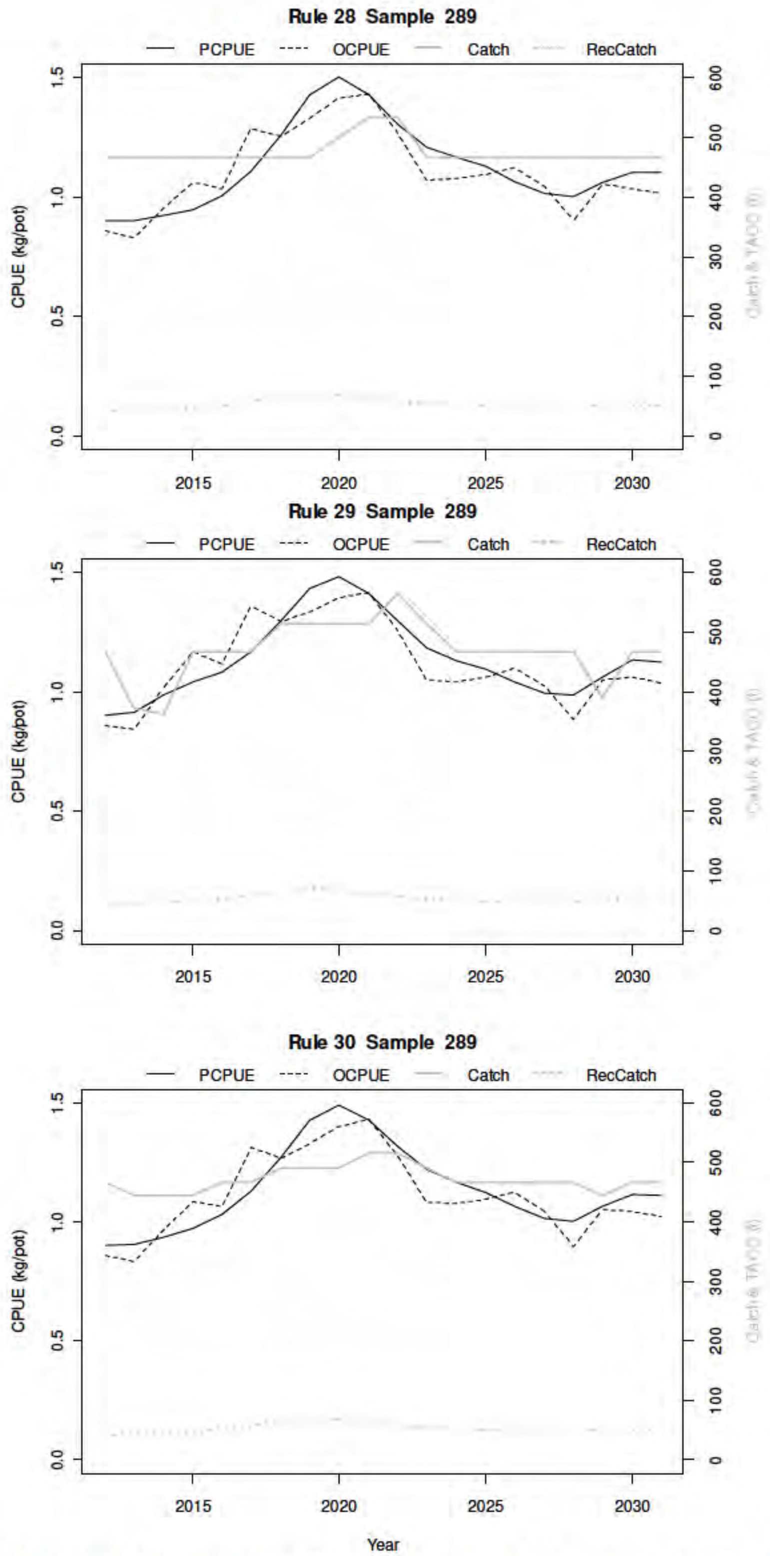

Figure 60: Trajectories of rules 28, 29 and 30 on sample 289: The solid black line is CPUE without observation error, the dashed black line is observed CPUE, the solid grey line is commercial catch (almost always equals TACC) and the lower dotted grey line is recreational catch.

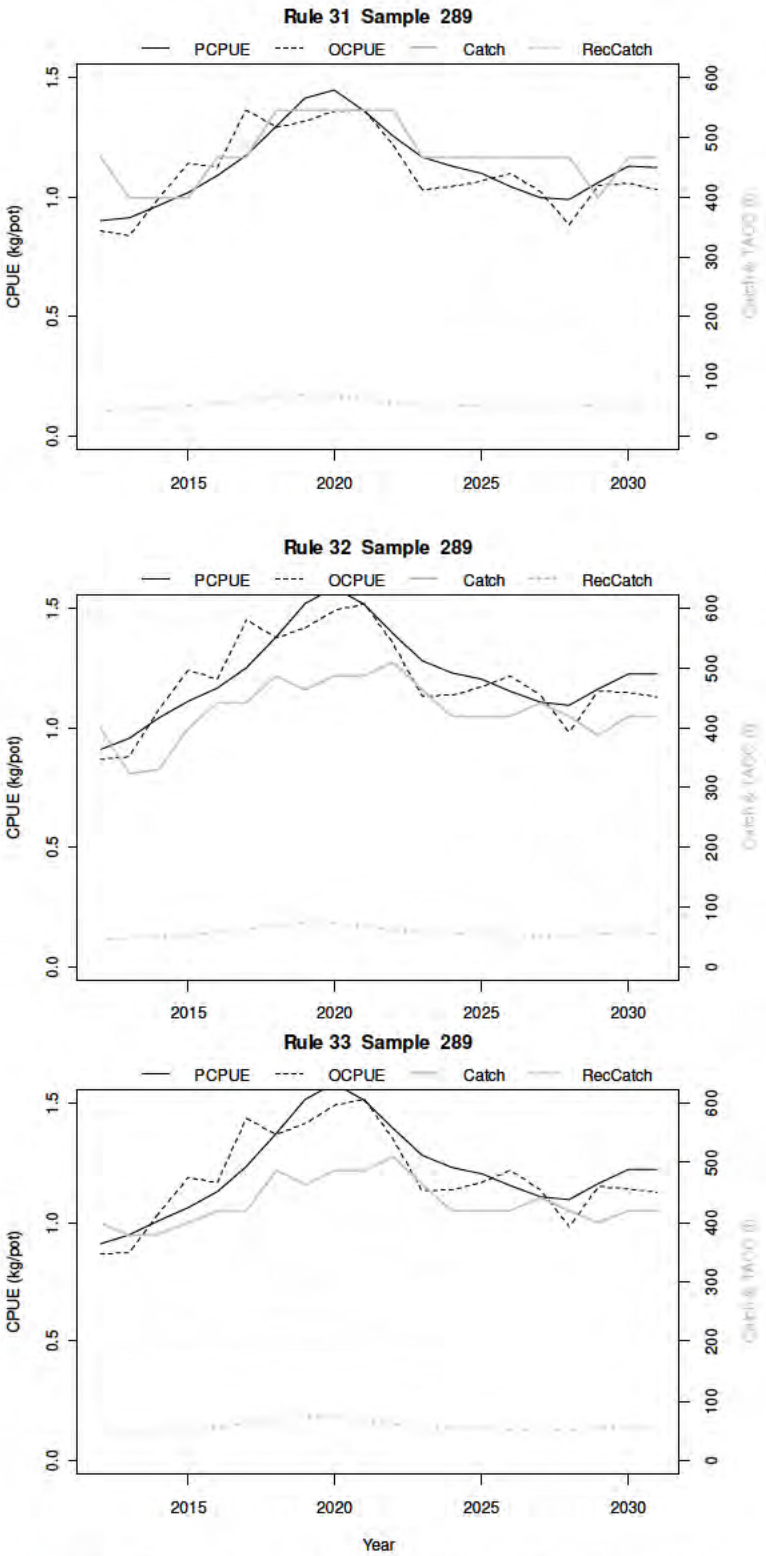

Figure 61: Trajectories of Rules 31, 32 and 33 on sample 289: The solid black line is CPUE without observation error, the dashed black line is observed CPUE, the solid grey line is commercial catch (almost always equals TACC) and the lower dotted grey line is recreational catch.

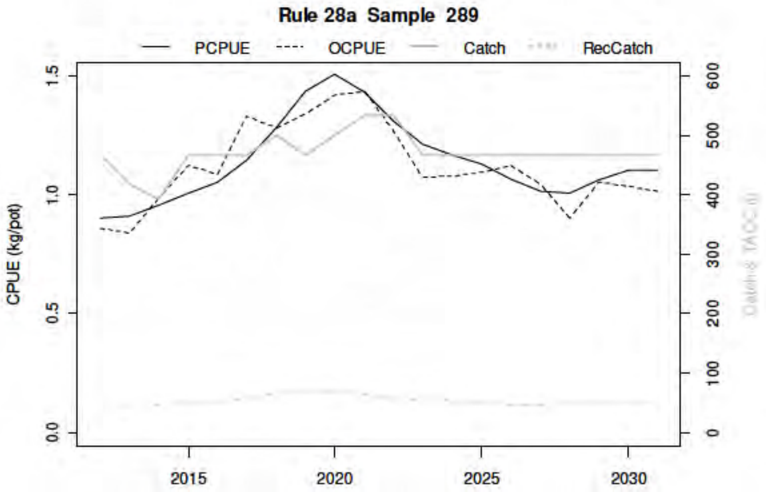

Figure 62: Trajectory of Rule 28a on sample 289.

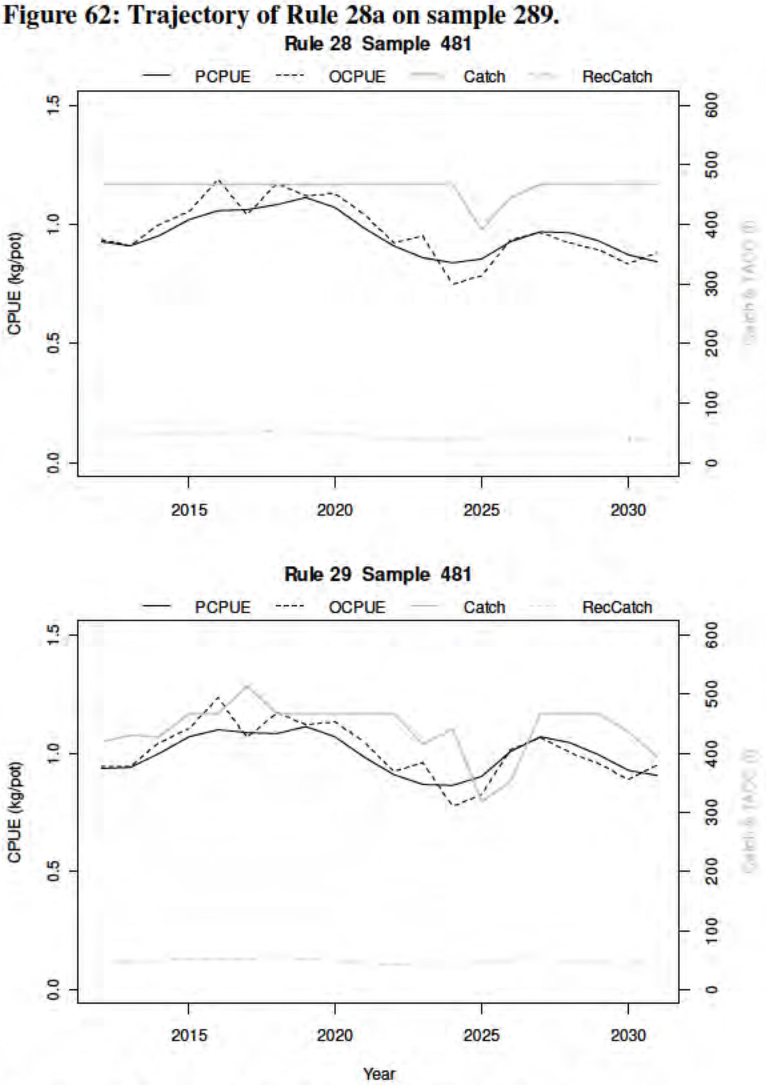

Figure 63: Trajectories of Rules 28 and 29 on sample 481.

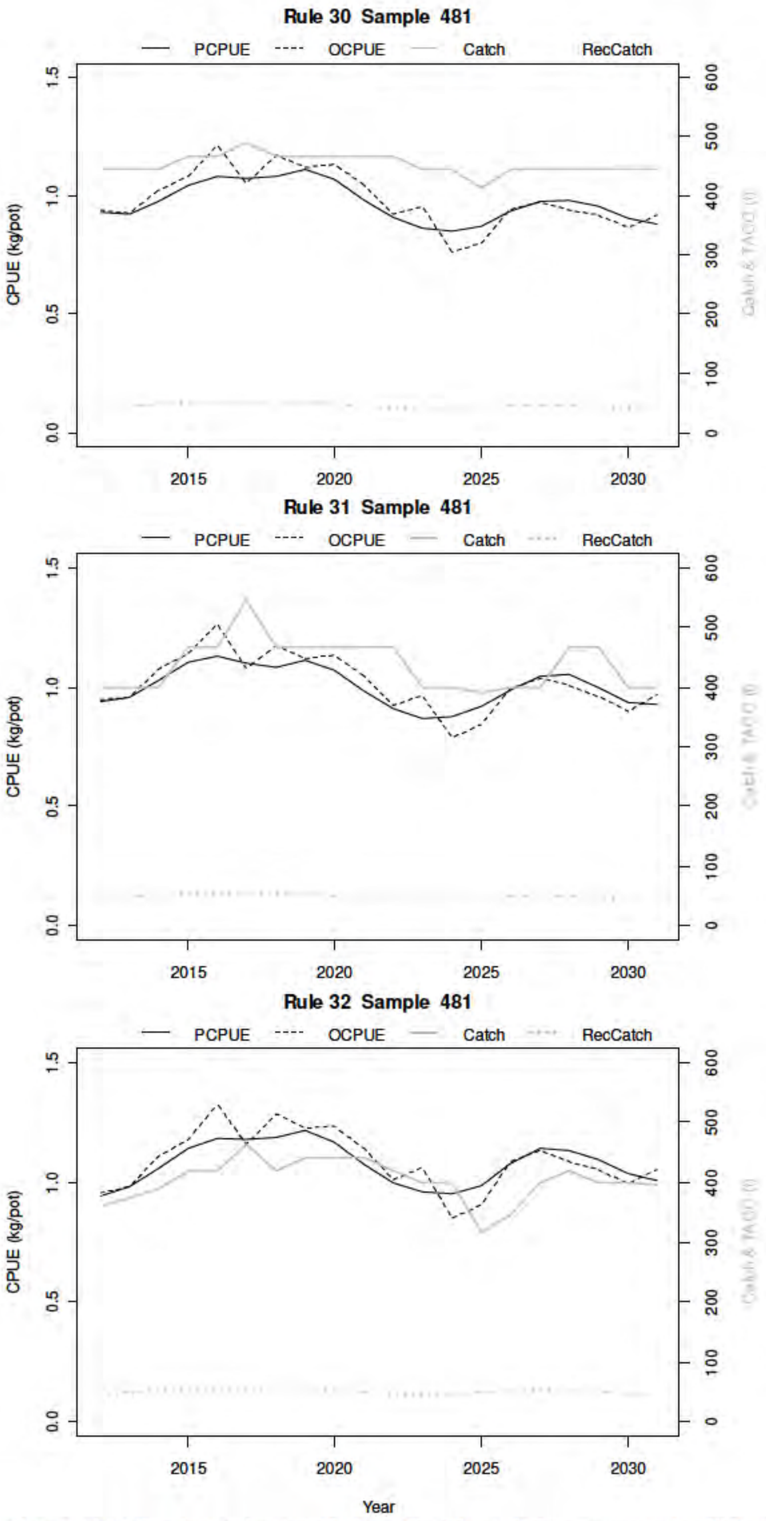

Figure 64: Trajectories of Rules 30, 31 and 32 on sample 481: The solid black line is CPUE without observation error, the dashed black line is observed CPUE, the solid grey line is commercial catch (almost always equals TACC) and the lower dotted grey line is recreational catch.

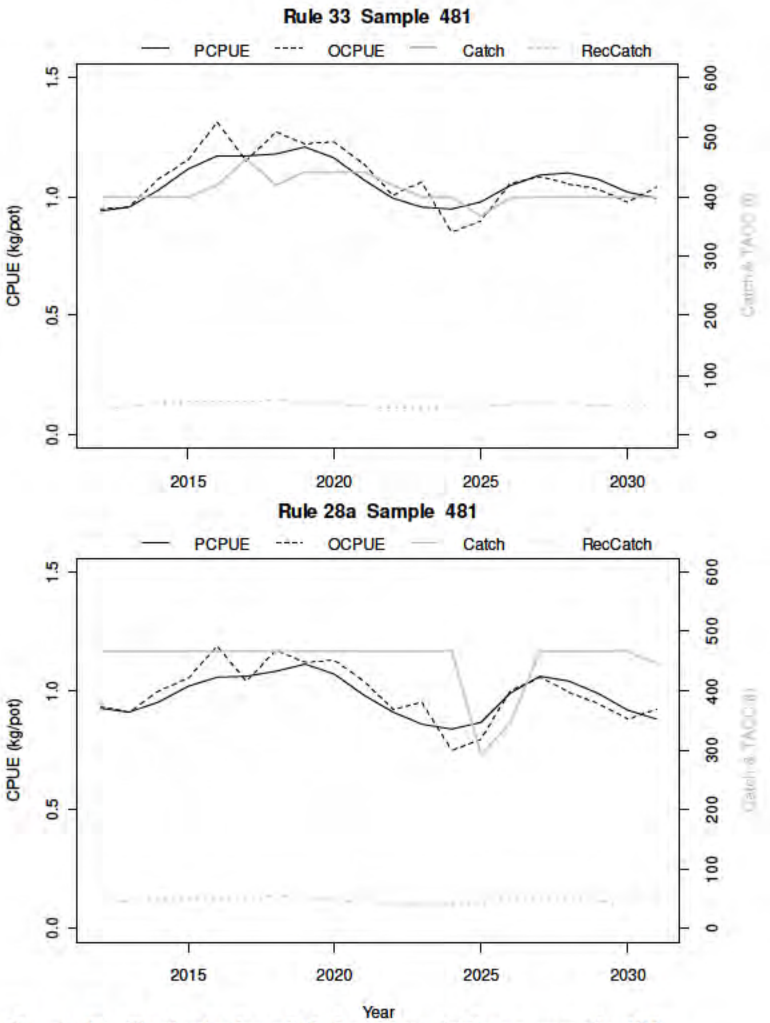

Figure 65: Trajectories of Rules 33 and 28a on sample 481.

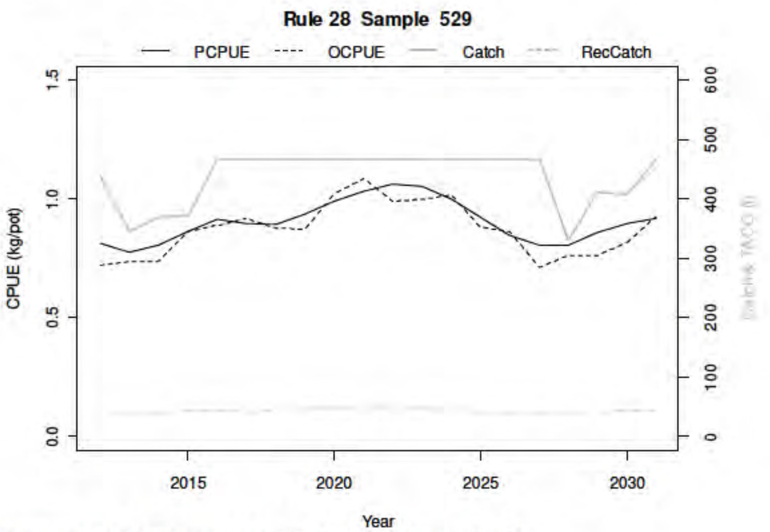

Figure 66: Trajectory of Rule 28 on sample 529.

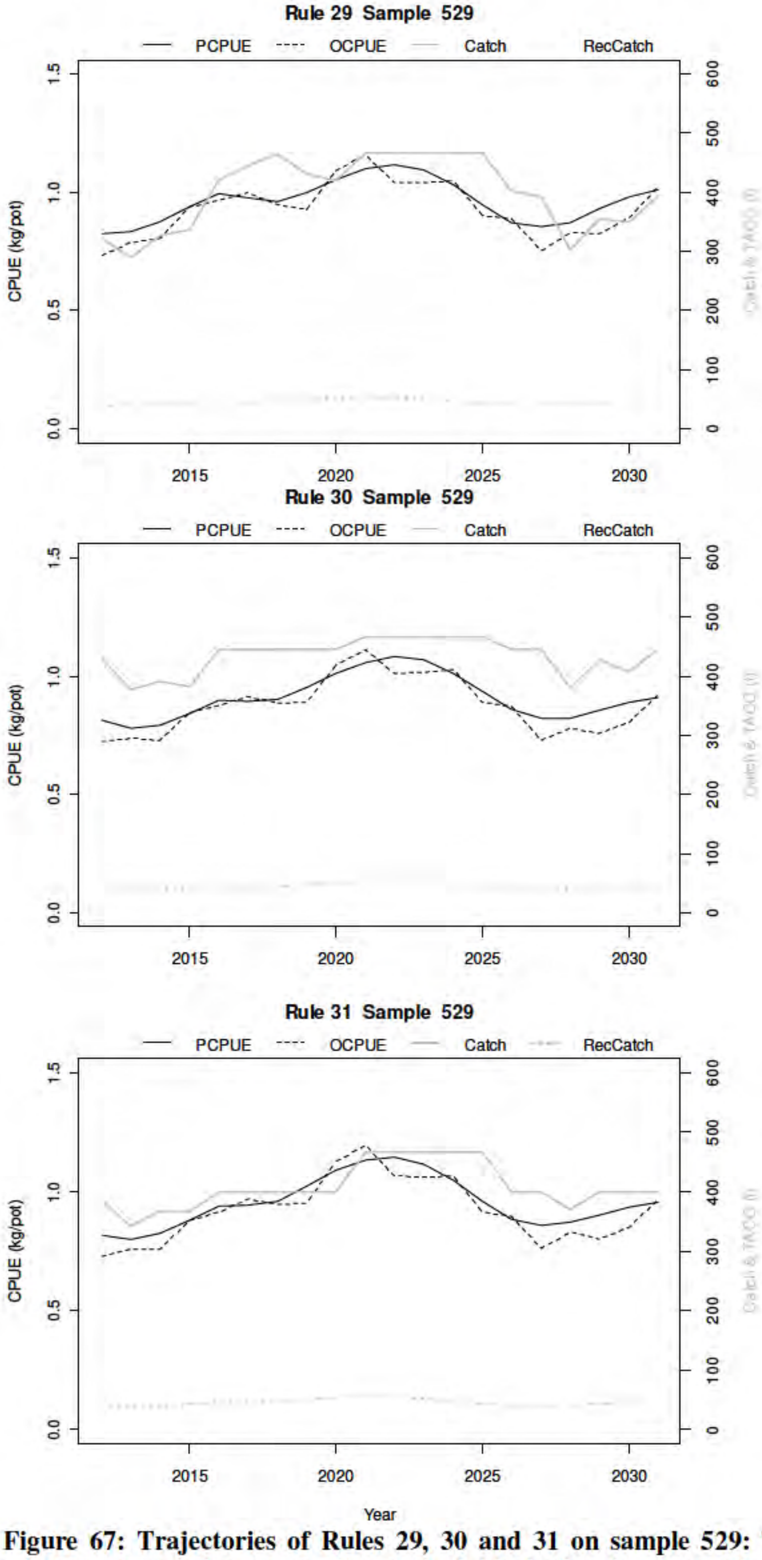

Figure 67: Trajectories of Rules 29, 30 and 31 on sample 529: The solid black line is CPUE without observation error, the dashed black line is observed CPUE, the solid grey line is commercial catch (almost always equals TACC) and the lower dotted grey line is recreational catch.

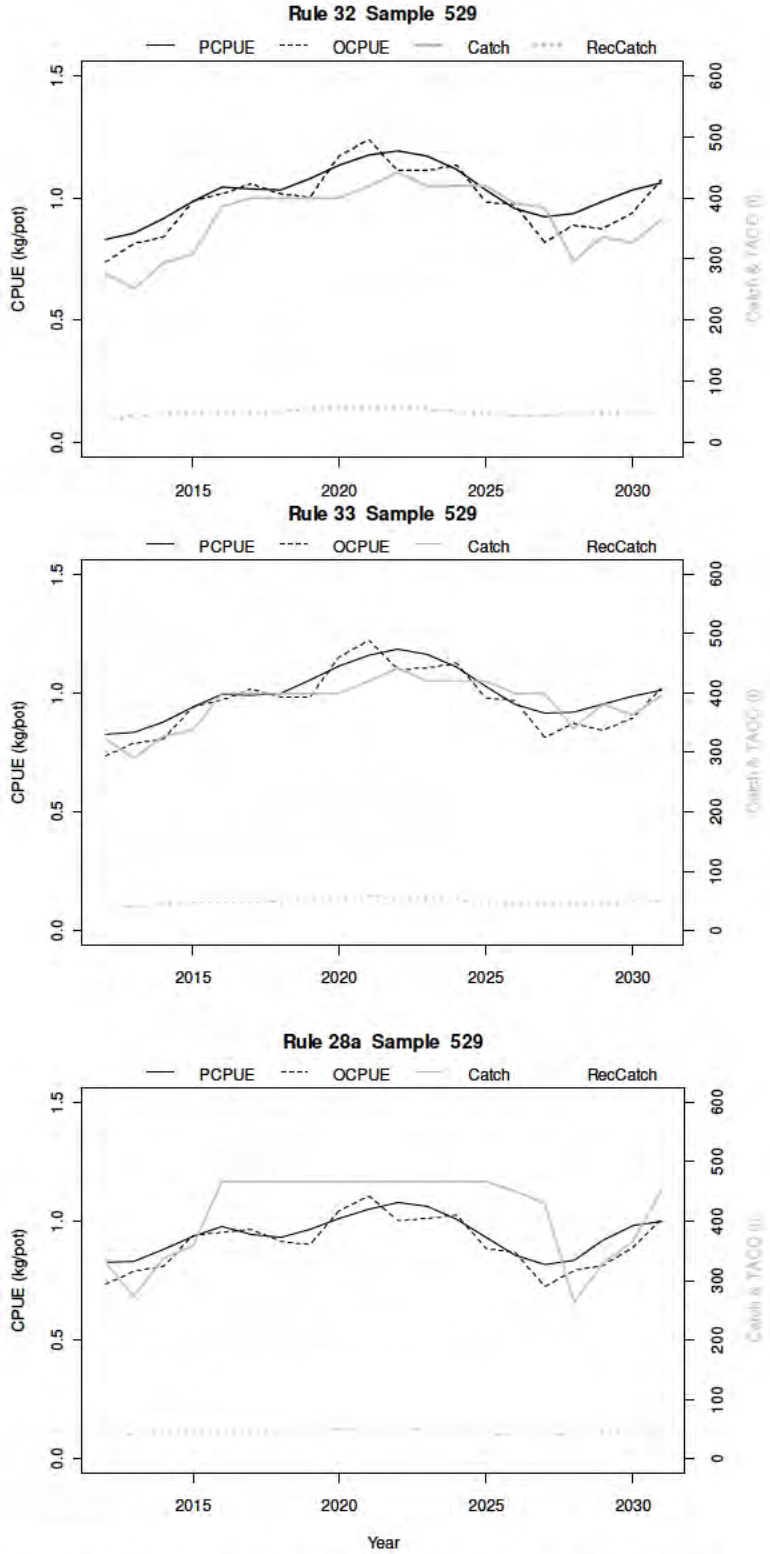

Figure 68: Trajectories of Rules 32, 33 and 28a on sample 529.

7.6.2 Robustness trials

As well as using the base case operating model, we used five alternative models in robustness trials:

- hiRect: recruitment was increased by 25% in every year;
- fixed$M$: with M fixed to 0.16; based on the fixed M McMC sensitivity trial;
- poolag3: based on the poolag3 McMC sensitivity trial;
- qinc: with catchability increasing by 1% per year;
- hiLFwt: with much higher weight on the LFs; based on the hiLFwt McMC sensitivity trial.

The high recruitment trial could be realistic if the pattern of recruitment changes. The period on which MPE recruitment was based was 2002–11, and in that period estimated recruitment was lower than recruitment for 1979–2001. Recruitment could increase at any time, and the hiRect trial indicates what to expect from the various rules.

The full results from robustness trials are given in Appendix B, Tables B2 through B7. Condensed results are shown here in Table 21 through Table 27.

7.6.2.1 Why poolag3 is less productive than the base case

Stock productivity implied by the poolag3 run was considerably less than in the base case trial (Table 21 through Table 27). A potential reason is that recruitment estimates were shifted with the different lags for the puerulus index and therefore the recruitments that form the basis of the recruitment projections (2002–2011) were different.

The recruitment estimates from the model fit with a lag of 3 were offset by two years from the base case, which had a lag of 1 (Figure 69). However, the 2002–2011 average recruitment for the poolag3 trial was only 13% less than for the base case (Table 20). The estimated average recruitment (*R0*) for the poolag3 trial was substantially lower (36%) than for the base case. Thus it was both the different recruitment period and the different estimated *R0* that caused the decreased productivity.

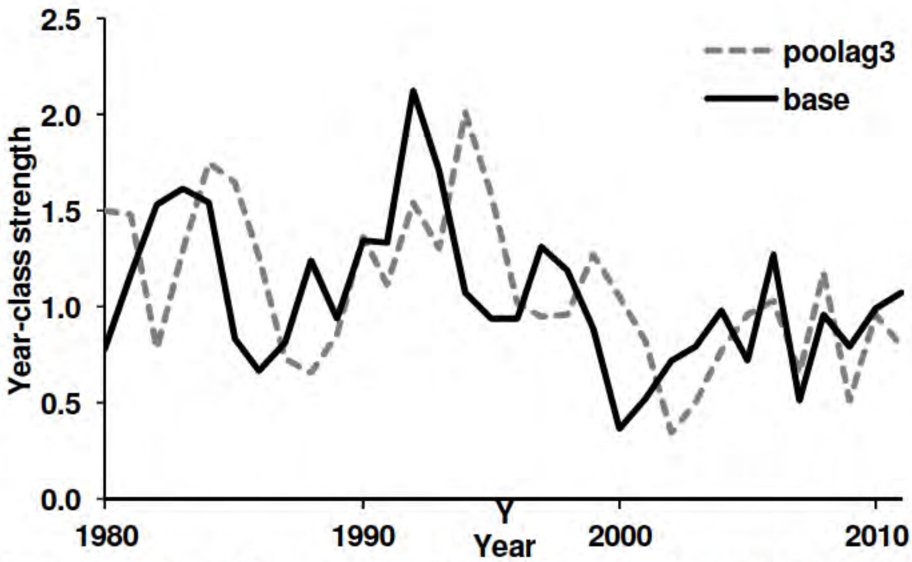

Figure 69: Median of the marginal posterior estimates of relative recruitment (labelled year class strength) for 1980–2011 from the base case and poolag3 model runs.

Table 20: Median of the marginal posterior estimates of average relative recruitment, 1980–2011, and *R0* for the base case and poolag3 model runs.

Model run	*R0*	Recruitment
base	491 x10^7	0.89
poolag3	316 x10^7	0.78

Table 21: Condensed results for Rule 28 in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE 1.1.1	Mean rec. catch 1.1.2	%AAV 1.1.3	CPUE <0.8 1.1.4	CPUE >1.2
28	base	457.3	0.904	44.3	3.6	11.8%	2.4%
28	hiRec	475.1	1.128	55.5	2.8	1.0%	39.5%
28	fixedM	451.1	0.896	42.7	5.1	15.7%	3.5%
28	poolag3	400.1	0.813	40.4	15.5	43.4%	1.3%
28	qinc	466.9	0.991	43.7	1.4	17.6%	1.8%
28	hiLFwt	447.4	0.883	44.8	6.0	18.9%	2.5%

Table 22: Condensed results for Rule 29 in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE	Mean rec. catch	%AAV	CPUE <0.8	CPUE >1.2
29	base	426.6	0.965	46.8	8.3	2.5%	3.2%
29	hiRec	471.3	1.143	56.1	6.0	0.1%	40.2%
29	fixedM	433.5	0.988	46.7	8.0	2.0%	5.4%
29	poolag3	374.5	0.871	42.8	11.8	23.8%	1.6%
29	qinc	448.6	1.033	45.2	6.4	8.6%	1.7%
29	hiLFwt	421.6	0.958	47.9	9.0	4.1%	3.5%

Table 23: Condensed results for Rule 30 in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE	Mean rec. catch	%AAV	CPUE <0.8	CPUE >1.2
30	base	446.9	0.925	45.2	2.6	9.5%	2.7%
30	hiRec	470.3	1.139	56.0	2.3	0.6%	40.7%
30	fixedM	446.5	0.926	44.0	2.6	11.5%	4.2%
30	poolag3	406.4	0.803	39.8	8.2	46.4%	1.1%
30	qinc	457.2	1.011	44.4	2.1	13.8%	2.0%
30	hiLFwt	441.9	0.902	45.5	3.3	15.6%	2.7%

Table 24: Condensed results for Rule 31 in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE	Mean rec. catch	%AAV	CPUE <0.8	CPUE >1.2
31	base	425.5	0.971	47.1	5.0	3.6%	3.6%
31	hiRec	471.1	1.144	56.1	5.7	0.2%	40.7%
31	fixedM	432.1	0.996	47.0	5.4	2.5%	6.0%
31	poolag3	386.7	0.849	41.9	7.4	32.1%	1.5%
31	qinc	443.5	1.044	45.6	5.5	8.0%	1.8%
31	hiLFwt	421.9	0.958	48.0	5.3	5.9%	3.7%

Table 25: Condensed results for Rule 32 in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE	Mean rec. catch	%AAV	CPUE <0.8	CPUE >1.2
32	base	391.5	1.040	50.0	6.6	0.3%	10.6%
32	hiRec	430.7	1.229	59.6	6.0	0.0%	58.6%
32	fixedM	408.1	1.116	52.0	6.0	0.1%	29.1%
32	poolag3	348.6	0.928	45.4	10.1	11.5%	3.8%
32	qinc	410.0	1.124	48.6	5.7	1.6%	6.5%
32	hiLFwt	391.3	1.046	51.8	7.0	0.5%	13.6%

Table 26: Condensed results for Rule 33 in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE	Mean rec. catch	%AAV	CPUE <0.8	CPUE >1.2
33	base	401.1	1.019	49.1	3.8	1.1%	9.2%
33	hiRec	435.3	1.216	59.1	4.6	0.0%	56.6%
33	fixedM	412.1	1.093	51.0	3.9	0.4%	24.2%
33	poolag3	366.7	0.888	43.6	8.1	20.4%	3.0%
33	qinc	414.9	1.110	48.1	3.8	2.9%	5.9%
33	hiLFwt	400.9	1.021	50.7	4.2	1.8%	11.0%

Table 27: Condensed results for Rule 28a in the base case and robustness trials.

Rule	Model	Mean catch	Mean CPUE	Mean rec. catch	%AAV	CPUE <0.8	CPUE >1.2
28a	base	438.7	0.939	45.7	7.6	4.8%	3.0%
28a	hiRec	468.8	1.146	56.1	4.9	0.4%	41.7%
28a	fixedM	439.3	0.953	45.2	7.8	5.1%	5.4%
28a	poolag3	380.5	0.858	42.4	16.7	27.3%	1.7%
28a	qinc	456.5	1.015	44.5	4.5	12.3%	1.9%
28a	hiLFwt	431.0	0.930	46.8	9.6	8.0%	3.5%

8. Discussion and conclusions

The stock assessment model fitted the data well and estimated reasonable parameter values, except that *M* was much higher than the mean of its prior distribution and the maturation ogive was estimated as wide. Not much is known with certainty about *M*, but a literature search conducted some time ago suggested that most lobster jurisdictions considered *M* to be in the 0.10–0.15 range. In the CRA 4 stock assessment, the high *M* was not a result of conflicting data sets: it occurred when each of the data sets was removed singly. Nor could we find any other simple modelling artefact that would cause estimates of *M* to be high. Because the signal in the data is strongly suggestive of high *M*, we accepted the estimates.

It may be that *M* aliases for emigration (there is no evidence of this from tag returns) or for decreased selectivity of older or larger fish. When estimated, the right-hand limb of the selectivity curve declines; this has happened in all lobster stock assessments and is considered dangerous to accept at face value because low selectivity at larger sizes allows the model population to contain large fish that cannot be caught.

The two different explanations for the lack of immature females in the LF data did not seem to be consequential for the stock assessment or for the MPEs. The RLFAWG considered the *base2* initial base case to be more credible than *base1*, but stock assessment conclusions were not sensitive to the choice of initial base case. Nor were they sensitive to other sensitivity trials that were taken through the McMC stage.

As we found in CRA 3 and CRA 5 (Breen et al. 2009a; Haist et al. 2011), the puerulus settlement data appeared to be consistent with the model's recruitment estimates. The randomisation tests appear to be far more powerful in detecting the signal than correlations analysis is, although in CRA 4 simpler analyses were able to demonstrate a good signal (P. Breen, unpublished data). Even when the model was not fitted to puerulus, there was high similarity between the model's recruitment and the settlement index. The short lags that give the best relation with settlement are too short to be biologically realistic, suggesting that the model over-estimates the time lobsters take to grow from 32 mm TW to MLS.

The stock assessment suggests that *Bref* is a more conservative reference point than *Bmsy*. With the high estimated *M*, the model suggests that MSY must be taken with quite high fishing intensity, resulting in a biomass that is lower than the minimum seen in the stock's history. With stakeholders wanting high abundance, *Bmsy* is an unrealistic reference point.

The stock assessment suggests that the current vulnerable stock is at least twice any of the biological reference points. Unless recruitment changes markedly from its recent pattern, the vulnerable stock is likely to decline slightly in the short term, but will remain above all reference levels with high certainty. Spawning stock biomass is a high fraction of its unfished value. Overall, there are no sustainability concerns for the stock.

Productivity of the operating model was lower than the historical catch and effort patterns of the stock would suggest: this was because of the lower recent recruitment compared with the longer-term average. The reasons for lower recruitment are unknown: they may relate to changes in ocean climate.

The productivity of the operating model, combined with the goals of stakeholders, dictated a narrow range of acceptable management procedure performance. Within the rules we tested, there was a strong relation between mean commercial catch and mean CPUE. Substantially decreased mean CPUE would be undesirable, and substantially increased mean CPUE would be associated with unacceptably low mean commercial catches. Accordingly, although we tried to find a range of rules to show stakeholders, the performances of the final rule set are quite similar. Any of these rules could be accepted.

The high stability of the rules we tested was due to the plateau form of the rules, which was first introduced to CRA 8 (Breen et al. 2009b).

9. Acknowledgements

This work was conducted under Objective 4 of MFish contract CRA2009-01B, awarded to the New Zealand Rock Lobster Industry Council Ltd. Thanks to Daryl Sykes, Helen Regan and Fiona McKay for their encouragement and assistance, to the RLFAWG members for helpful discussions, to the stakeholders in CRA 4 for their input into management procedure development and to Marianne Vignaux for editorial improvements.

10. References

Breen, P.A.; Haist, V.; Starr, P.J.; Kendrick, T.H. (2009a). The 2008 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 3. *New Zealand Fisheries Assessment Report 2009/23*. 54 p.

Breen, P.A.; Starr, P.J.; Haist, V. (2009b). New Zealand decision rules and management procedures for rock lobsters. *New Zealand Fisheries Assessment Report 2009/43*. 18 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68(6)*: 1124-1138.

Haist, V.; Breen, P.A.; Starr, P.J. (2009). A new multi-stock length-based assessment model for New Zealand rock lobsters (*Jasus edwardsii*). *New Zealand Journal of Marine and Freshwater Research 43(1)*: 355–371.

Haist, V.; Breen, P.A.; Starr, P.J.; Kendrick, T.H. (2011). The 2010 stock assessment of red rock lobsters (Jasus edwardsii) in CRA 5, and development of an operational management procedure. *New Zealand Fisheries Assessment Report 2011/12*. 68 p.

Schnute, J. (1981). A versatile growth model with statistically stable parameters. *Canadian Journal of Fisheries and Aquatic Sciences 38*: 1128–1140.

Starr, P.J. (2011). Rock lobster catch and effort data: summaries and CPUE standardisations, 1979–80 to 2009–10. *New Zealand Fisheries Assessment Report 2011/18*. 85 p.

Starr, P.J.; Breen, P.A.; Haist, V.; Pomarede, M. (2012). Data for the 2011 stock assessment of red rock lobsters (Jasus edwardsii) in CRA 4. *New Zealand Fisheries Assessment Report 2012/08*. 48 p.

Appendix A: CRA 4 offset year CPUE

Standardised offset year CRA 4 CPUE was estimated from data obtained from MFish in August 2011 (Replog 8227) and handled as described by Starr et al. (2012); numbers of records are shown in Table A.1.

Standardisation used the offset year as the time-dependent explanatory variable, ending with the last complete offset year 2010 (1 October 2009 to 30 September 2010). Other explanatory variables offered were month and statistical area. The index values and associated standard errors are provided in Table A.2; deviance explained by each variable is given in Table A.3; model residuals are shown in Figure A.1. Influence plots for month are provided in Figure A.2 and for statistical area in Figure A.3. A stepwise graph, showing the effect on the year variable with the addition of each model explanatory variable, is given in Figure A.4 and standardised CPUE is shown in Figure A.5.

Table A.1. Number of vessel/statistical area/month records in the dataset used to calculate the offset year CRA 4 CPUE time series. '–': no data for indicated cell

	CRA 4 Statistical Area					
Offset year	912	913	914	915	934	Total
1980	237	193	238	157	2	827
1981	258	162	238	165	7	830
1982	268	142	239	161	2	812
1983	256	182	278	182	5	903
1984	236	202	294	174	8	914
1985	230	173	283	162	6	854
1986	235	164	289	164	8	860
1987	225	183	277	138	6	829
1988	215	165	287	133	5	805
1989	200	183	278	112	–	773
1990	216	196	286	109	5	812
1991	230	201	297	111	5	844
1992	265	217	270	103	7	862
1993	281	220	259	106	13	879
1994	195	205	250	102	17	769
1995	139	170	224	76	15	624
1996	136	124	191	76	5	532
1997	123	65	167	46	–	401
1998	107	49	161	50	–	367
1999	108	66	168	59	4	405
2000	129	50	126	52	12	369
2001	121	77	130	63	15	406
2002	131	106	143	61	4	445
2003	119	110	162	71	–	462
2004	119	110	165	80	5	479
2005	121	108	166	70	9	474
2006	97	100	202	95	13	507
2007	98	99	214	100	27	538
2008	88	85	163	77	23	436
2009	80	86	128	51	10	355
2010	97	75	133	82	15	402

Table A.2. Offset year CPUE indices; arithmetic index: sum of annual catch divided by the sum of annual potlifts; unstandardised index: geometric mean of the CPUE observations by year; standardised index: annual index after removal of month and statistical area effects, scaled by the geometric mean of the data, which was 83 kg/potlift.

Offset year	Arithmetic Index	Unstandardised Index	Standardised Index	Lower Bound	Upper Bound	Standard Error
1980	0.89	0.87	0.84	0.81	0.87	0.021
1981	0.82	0.83	0.81	0.77	0.84	0.021
1982	0.85	0.89	0.89	0.85	0.92	0.021
1983	0.93	0.92	0.90	0.86	0.93	0.020
1984	0.84	0.81	0.79	0.76	0.82	0.020
1985	0.72	0.71	0.70	0.67	0.72	0.020
1986	0.75	0.77	0.75	0.72	0.78	0.020
1987	0.81	0.74	0.71	0.69	0.74	0.021
1988	0.69	0.65	0.63	0.61	0.66	0.021
1989	0.61	0.56	0.54	0.52	0.57	0.021
1990	0.57	0.55	0.53	0.51	0.55	0.021
1991	0.49	0.51	0.50	0.48	0.52	0.020
1992	0.52	0.51	0.49	0.47	0.51	0.020
1993	0.54	0.53	0.51	0.49	0.53	0.020
1994	0.64	0.64	0.63	0.60	0.65	0.021
1995	0.81	0.78	0.77	0.74	0.81	0.023
1996	1.01	1.07	1.11	1.05	1.16	0.025
1997	1.24	1.28	1.37	1.29	1.45	0.029
1998	1.29	1.37	1.51	1.42	1.60	0.030
1999	1.28	1.40	1.53	1.44	1.62	0.029
2000	1.23	1.12	1.22	1.15	1.29	0.031
2001	1.08	1.06	1.15	1.09	1.22	0.029
2002	1.03	1.07	1.13	1.07	1.19	0.028
2003	1.14	1.20	1.24	1.17	1.31	0.028
2004	0.99	0.97	1.00	0.95	1.05	0.028
2005	1.04	1.00	0.98	0.93	1.03	0.028
2006	0.77	0.76	0.76	0.72	0.80	0.027
2007	0.65	0.67	0.65	0.61	0.68	0.026
2008	0.61	0.63	0.61	0.58	0.65	0.029
2009	0.82	0.89	0.85	0.80	0.91	0.033
2010	0.96	0.97	1.00	0.94	1.06	0.031

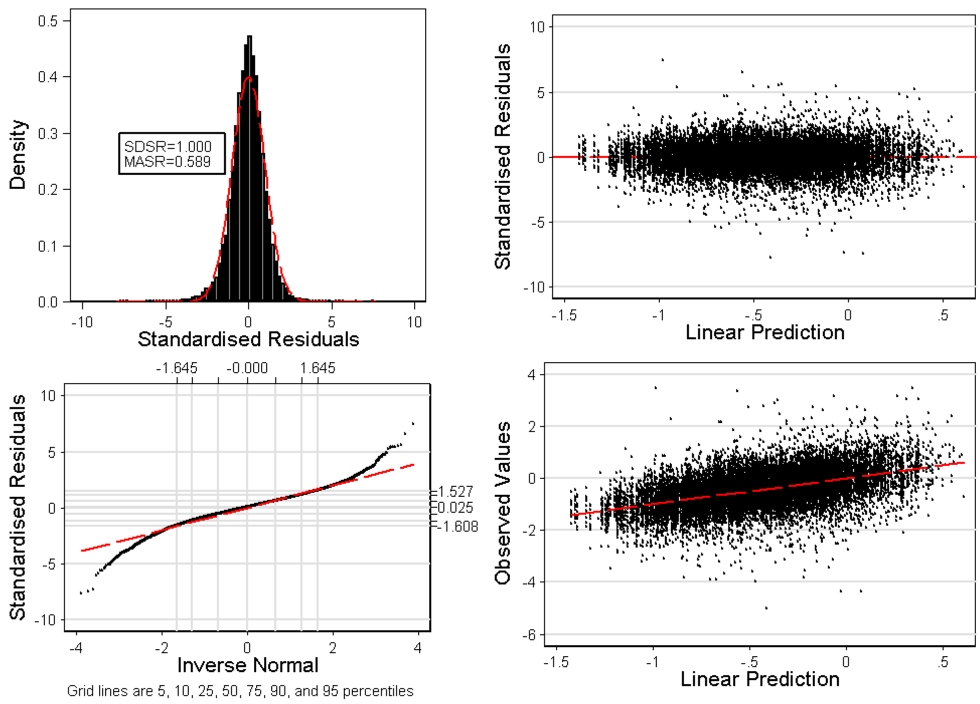

Figure A.1: Standardised residual plots for the CRA 4 standardised offset year CPUE analysis.

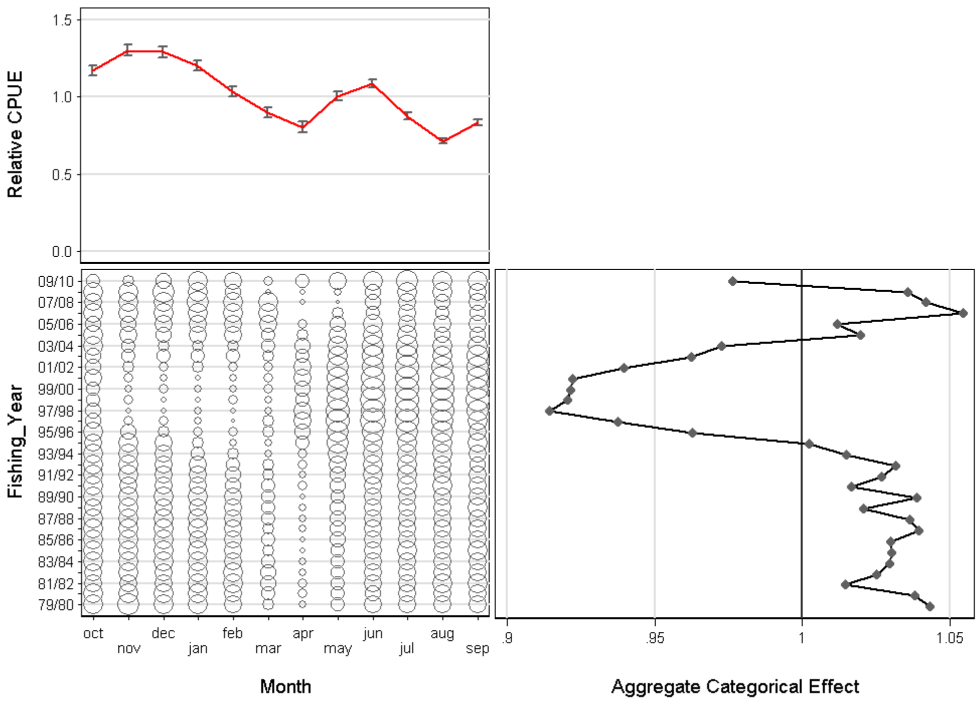

Figure A.2: The effect of month in the standardisation model: top left: effect by level of variable; bottom left: distribution of variable by year; bottom right: cumulative effect of variable by year.

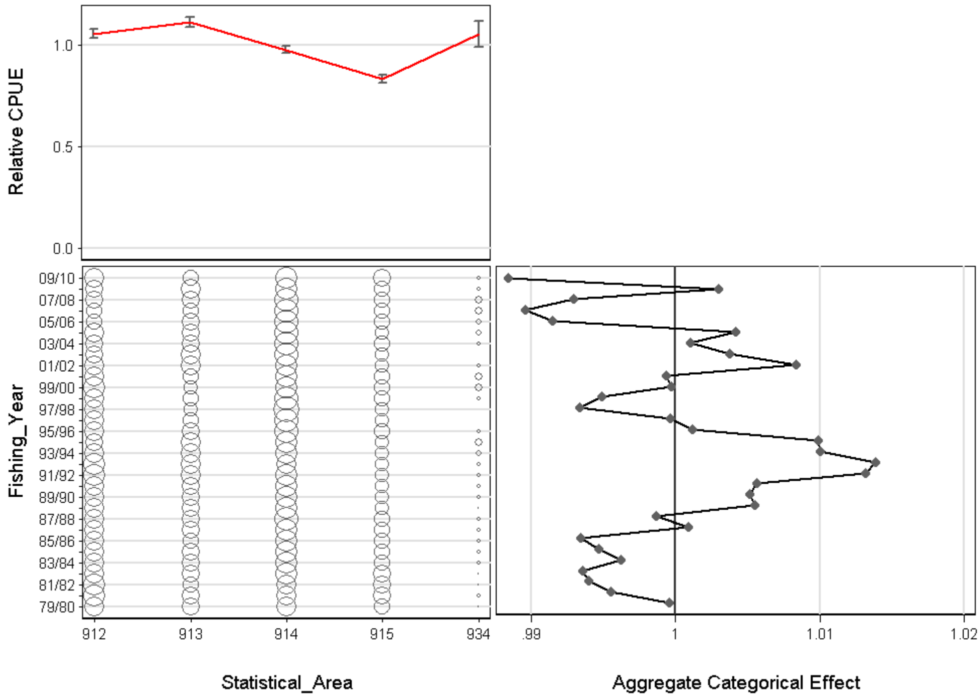

Figure A.3: The effect of statistical area in the standardisation model: top left: effect by level of variable; bottom left: distribution of variable by year; bottom right: cumulative effect of variable by year.

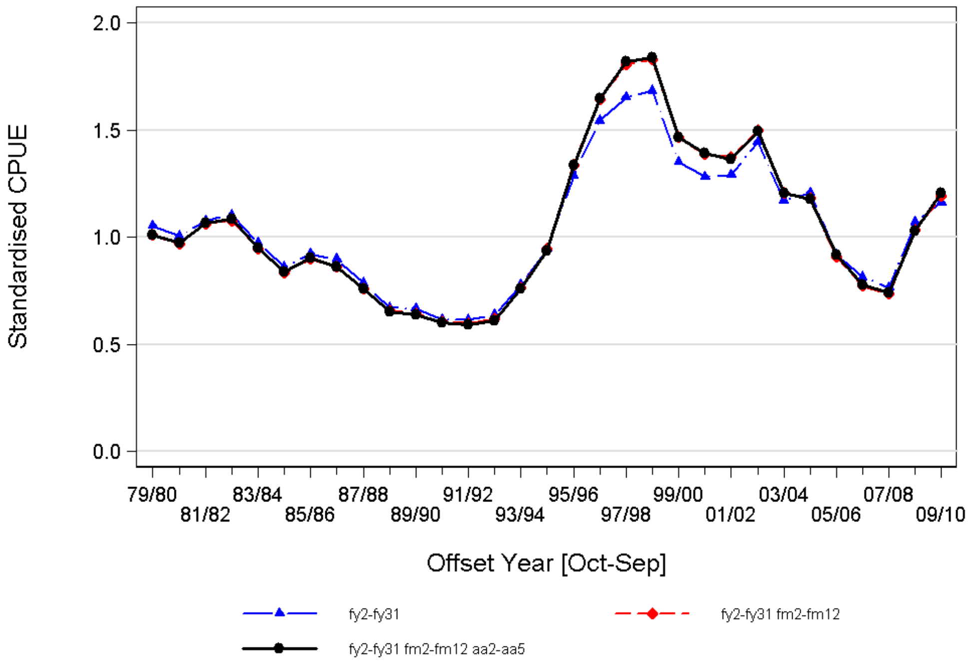

Figure A.4: Stepwise graph showing the effect on the year coefficients from the successive addition of each variable to the standardisation model. The final model is shown by a thick heavy line.

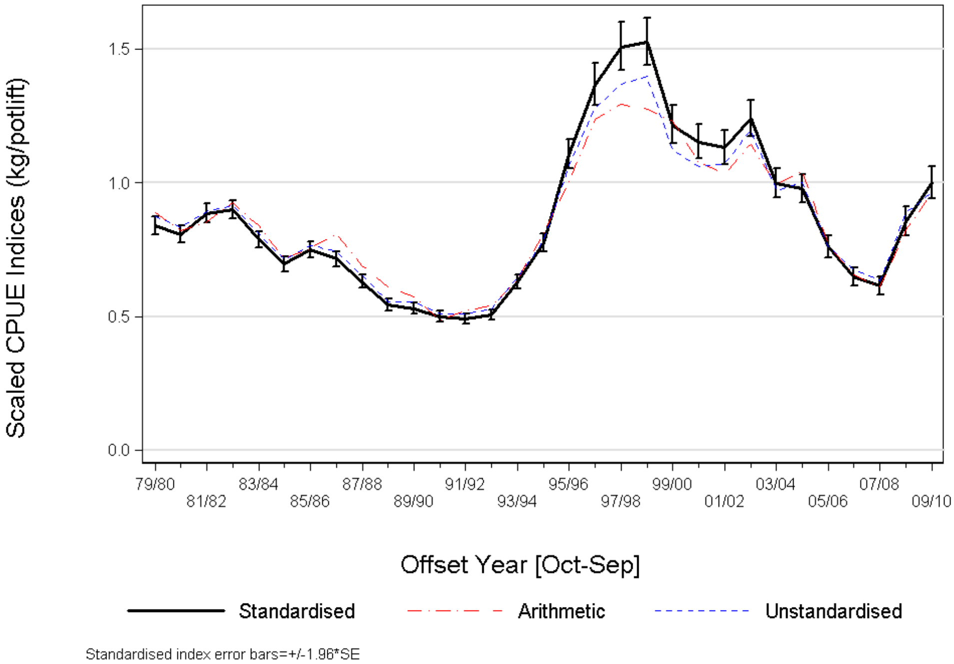

Figure A.5: Offset year CPUE indices for CRA 4: arithmetic (dashed line), unstandardised (dotted line), and standardised (bold line) ± 2 s.e. from 1979–80 to 2009–10. The geometric mean for each series was 0.83 kg/potlift.

Table A.3. Total deviance (R^2) explained by each variable in the CRA 4 standardised offset year CPUE analysis

Variable	1	2	3
Fishing Year	0.1580		
Month	0.0499	0.2331	
Statistical Area	0.0162	0.1777	0.2522
Additional deviance explained	0.0000	0.0751	0.0191

Appendix B: Detailed indicators from seven rules.

Table B1: Base case MPEs.

Base	Indicator	28	29	30	31	32	33	28a
av(Bio/Bref)	5%	1.352	1.441	1.357	1.434	1.543	1.493	1.406
av(Bio/Bref)	median	1.563	1.659	1.594	1.660	1.773	1.737	1.619
av(Bio/Bref)	95%	1.873	1.913	1.892	1.924	2.047	2.031	1.902
terminal(Bio/Bref)	5%	1.172	1.272	1.191	1.262	1.380	1.328	1.238
terminal(Bio/Bref)	median	1.552	1.637	1.557	1.630	1.752	1.718	1.603
terminal(Bio/Bref)	95%	2.051	2.107	2.069	2.128	2.248	2.226	2.094
minCommCatch	5%	191.5	261.7	291.2	297.9	252.8	274.9	198.9
minCommCatch	median	356.9	327.4	400.8	396.2	308.6	349.0	310.2
minCommCatch	95%	466.9	390.9	444.9	400.0	364.3	399.9	427.4
avCatch	5%	418.8	386.8	420.9	397.6	358.7	377.2	396.7
avCatch	median	457.3	426.6	446.9	425.5	391.5	401.1	438.7
avCatch	95%	469.3	462.3	464.9	458.0	422.0	426.5	466.4
av5yrCatch	5%	430.5	375.1	429.2	393.8	336.2	367.6	385.3
av5yrCatch	median	466.9	413.5	445.0	413.3	369.7	393.7	437.7
av5yrCatch	95%	467.0	450.3	453.9	440.1	398.5	404.0	466.9
minRecCatch	5%	32.1	35.4	32.3	34.6	37.9	36.5	34.4
minRecCatch	median	38.0	40.4	39.0	40.6	42.4	41.9	39.3
minRecCatch	95%	44.0	44.8	44.4	45.3	46.7	46.3	44.1
avRecCatch	5%	39.9	42.8	40.0	42.2	45.4	43.8	41.9
avRecCatch	median	44.3	46.8	45.2	47.1	50.0	49.1	45.7
avRecCatch	95%	52.3	53.1	52.7	53.3	56.7	56.3	52.7
minCPUE	5%	0.623	0.691	0.625	0.671	0.742	0.710	0.669
minCPUE	median	0.726	0.788	0.746	0.791	0.840	0.822	0.764
minCPUE	95%	0.864	0.886	0.877	0.899	0.943	0.938	0.866
avCPUE	5%	0.819	0.887	0.821	0.868	0.946	0.910	0.866
avCPUE	median	0.904	0.965	0.925	0.971	1.040	1.019	0.939
avCPUE	95%	1.068	1.088	1.079	1.096	1.175	1.164	1.082
%AAV	5%	0.0	4.2	1.0	2.4	3.8	1.5	1.4
%AAV	median	3.6	8.3	2.6	5.0	6.6	3.8	7.6
%AAV	95%	12.6	12.2	6.7	8.4	10.2	7.2	15.7
Mean(Bvulnref/Bmsy)	5%	1.798	1.925	1.813	1.910	2.062	2.008	1.884
Mean(Bvulnref/Bmsy)	median	2.142	2.264	2.184	2.271	2.422	2.375	2.215
Mean(Bvulnref/Bmsy)	95%	2.581	2.687	2.629	2.713	2.871	2.845	2.641
	P<Bref	0.003	0.001	0.002	0.001	0.000	0.000	0.001
	P<Bmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<Bmsy	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	nchanges	0.298	0.811	0.461	0.416	0.804	0.571	0.539
	P<SSB20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<SSB10%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CPUE>0.6	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	CPUE>0.7	0.988	0.999	0.989	0.998	1.000	1.000	0.999
	CPUE>0.8	0.882	0.975	0.905	0.964	0.997	0.989	0.952
	CPUE>0.9	0.539	0.767	0.608	0.767	0.917	0.864	0.672
	CPUE>1	0.214	0.376	0.263	0.397	0.651	0.564	0.297
	CPUE>1.1	0.076	0.120	0.090	0.135	0.320	0.268	0.100
	CPUE>1.2	0.024	0.032	0.027	0.036	0.106	0.092	0.030

Table B2: MPEs from the hiRect robustness trial.

hiRect	Indicator	28	29	30	31	32	33	28a
av(Bio/Bref)	5%	1.649	1.705	1.668	1.714	1.824	1.803	1.681
av(Bio/Bref)	median	1.950	1.974	1.966	1.976	2.106	2.085	1.976
av(Bio/Bref)	95%	2.288	2.301	2.334	2.284	2.454	2.431	2.301
terminal(Bio/Bref)	5%	1.586	1.599	1.616	1.597	1.735	1.717	1.606
terminal(Bio/Bref)	median	2.085	2.059	2.103	2.050	2.200	2.200	2.087
terminal(Bio/Bref)	95%	2.735	2.669	2.752	2.649	2.831	2.831	2.729
minCommCatch	5%	333.7	302.1	380.0	359.8	273.7	309.3	269.2
minCommCatch	median	466.8	359.6	444.9	399.9	326.2	372.6	371.3
minCommCatch	95%	466.9	420.8	445.0	400.0	378.2	400.0	466.9
avCatch	5%	459.4	440.0	453.7	440.1	401.4	409.8	446.7
avCatch	median	475.1	471.3	470.3	471.1	430.7	435.3	468.8
avCatch	95%	511.5	510.2	492.6	515.3	469.3	472.9	508.5
av5yrCatch	5%	430.7	375.3	429.2	393.8	336.5	367.8	385.7
av5yrCatch	median	466.9	413.9	444.9	413.3	369.7	393.9	437.8
av5yrCatch	95%	467.0	450.6	454.1	440.1	398.6	404.0	466.9
minRecCatch	5%	37.5	38.9	38.2	39.1	40.1	39.6	38.3
minRecCatch	median	41.7	42.5	42.1	42.7	43.6	43.2	41.9
minRecCatch	95%	45.5	46.1	45.8	46.4	47.2	46.9	45.6
avRecCatch	5%	48.3	50.1	49.2	50.4	53.7	53.1	49.5
avRecCatch	median	55.5	56.1	56.0	56.1	59.6	59.1	56.1
avRecCatch	95%	63.6	63.9	65.4	63.4	67.7	67.4	64.1
minCPUE	5%	0.714	0.753	0.727	0.750	0.781	0.764	0.731
minCPUE	median	0.808	0.840	0.824	0.849	0.877	0.863	0.820
minCPUE	95%	0.923	0.935	0.934	0.946	0.971	0.966	0.923
avCPUE	5%	0.975	1.022	0.992	1.025	1.101	1.084	1.005
avCPUE	median	1.128	1.143	1.139	1.144	1.229	1.216	1.146
avCPUE	95%	1.294	1.301	1.334	1.287	1.397	1.386	1.301
%AAV	5%	0.0	3.6	1.1	3.0	4.0	2.6	1.8
%AAV	median	2.8	6.0	2.3	5.7	6.0	4.6	4.9
%AAV	95%	6.5	9.3	3.9	8.9	8.6	7.0	9.2
Mean(Bvulnref/Bmsy)	5%	2.205	2.281	2.235	2.281	2.435	2.402	2.250
Mean(Bvulnref/Bmsy)	median	2.668	2.699	2.699	2.700	2.878	2.859	2.700
Mean(Bvulnref/Bmsy)	95%	3.202	3.222	3.248	3.214	3.429	3.405	3.232
	P<Bref	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<Bmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<Bmsy	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	nchanges	0.326	0.629	0.464	0.415	0.770	0.663	0.466
	P<SSB20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<SSB10%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CPUE>0.6	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	CPUE>0.7	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	CPUE>0.8	0.990	0.999	0.994	0.998	1.000	1.000	0.996
	CPUE>0.9	0.849	0.924	0.879	0.926	0.966	0.949	0.890
	CPUE>1	0.688	0.771	0.718	0.776	0.853	0.821	0.735
	CPUE>1.1	0.550	0.601	0.574	0.612	0.742	0.711	0.586
	CPUE>1.2	0.395	0.402	0.407	0.407	0.586	0.566	0.417

Table B3: MPEs from the fixedM robustness trial.

fixedM	Indicator	28	29	30	31	32	33	28a
av(Bio/Bref)	5%	1.135	1.256	1.146	1.245	1.384	1.334	1.218
av(Bio/Bref)	median	1.338	1.461	1.370	1.467	1.617	1.587	1.420
av(Bio/Bref)	95%	1.676	1.738	1.708	1.749	1.922	1.898	1.726
terminal(Bio/Bref)	5%	0.959	1.084	0.980	1.057	1.213	1.167	1.044
terminal(Bio/Bref)	median	1.314	1.422	1.332	1.420	1.578	1.557	1.380
terminal(Bio/Bref)	95%	1.841	1.918	1.836	1.939	2.089	2.079	1.908
minCommCatch	5%	159.6	267.2	276.3	303.8	268.0	292.5	193.8
minCommCatch	median	330.3	328.2	397.3	399.9	321.2	363.9	304.7
minCommCatch	95%	466.9	392.5	444.9	400.0	378.3	400.0	424.7
avCatch	5%	410.7	396.5	414.8	400.9	378.5	388.3	400.3
avCatch	median	451.1	433.5	446.5	432.1	408.1	412.1	439.3
avCatch	95%	470.1	467.0	466.4	465.2	437.7	440.0	466.9
av5yrCatch	5%	415.7	375.2	423.9	394.8	343.2	369.1	379.1
av5yrCatch	median	464.2	413.2	445.0	413.4	375.4	394.8	430.0
av5yrCatch	95%	467.0	448.4	453.9	440.2	401.9	408.0	466.9
minRecCatch	5%	31.1	35.7	31.7	34.7	37.9	37.1	34.1
minRecCatch	median	36.4	39.5	37.8	39.8	41.5	41.0	38.3
minRecCatch	95%	42.0	43.1	42.8	43.7	45.0	44.6	42.4
avRecCatch	5%	38.5	42.3	38.5	41.6	46.6	44.6	41.1
avRecCatch	median	42.7	46.7	44.0	47.0	52.0	51.0	45.2
avRecCatch	95%	51.5	52.6	52.1	52.8	58.5	57.9	52.7
minCPUE	5%	0.600	0.699	0.609	0.674	0.769	0.737	0.663
minCPUE	median	0.708	0.789	0.741	0.802	0.866	0.846	0.758
minCPUE	95%	0.861	0.889	0.886	0.913	0.974	0.969	0.864
avCPUE	5%	0.810	0.904	0.808	0.887	0.999	0.950	0.874
avCPUE	median	0.896	0.988	0.926	0.996	1.116	1.093	0.953
avCPUE	95%	1.086	1.111	1.106	1.123	1.250	1.238	1.118
%AAV	5%	0.0	4.0	1.0	2.8	3.6	1.8	1.5
%AAV	median	5.1	8.0	2.6	5.4	6.0	3.9	7.8
%AAV	95%	15.7	12.4	7.8	8.6	9.3	6.9	16.3
Mean(Bvulnref/Bmsy)	5%	0.987	1.086	0.994	1.074	1.199	1.168	1.056
Mean(Bvulnref/Bmsy)	median	1.188	1.291	1.215	1.297	1.433	1.403	1.261
Mean(Bvulnref/Bmsy)	95%	1.494	1.535	1.512	1.553	1.692	1.679	1.522
	P<Bref	0.050	0.010	0.038	0.012	0.001	0.002	0.020
	P<Bmin	0.001	0.000	0.001	0.000	0.000	0.000	0.000
	P<Bmsy	0.171	0.069	0.141	0.066	0.016	0.022	0.100
	nchanges	0.354	0.768	0.480	0.423	0.767	0.602	0.524
	P<SSB20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<SSB10%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CPUE>0.6	0.999	1.000	1.000	1.000	1.000	1.000	1.000
	CPUE>0.7	0.980	0.999	0.984	0.998	1.000	1.000	0.998
	CPUE>0.8	0.843	0.980	0.885	0.975	0.999	0.996	0.949
	CPUE>0.9	0.508	0.802	0.594	0.808	0.958	0.924	0.692
	CPUE>1	0.228	0.469	0.287	0.489	0.801	0.729	0.371
	CPUE>1.1	0.096	0.191	0.117	0.209	0.564	0.487	0.159
	CPUE>1.2	0.035	0.054	0.042	0.060	0.291	0.242	0.054

Table B4: MPEs from the poolag3 robustness trial.

poolag3	Indicator	28	29	30	31	32	33	28a
av(Bio/Bref)	5%	1.254	1.322	1.215	1.274	1.400	1.338	1.323
av(Bio/Bref)	median	1.430	1.521	1.411	1.485	1.613	1.552	1.503
av(Bio/Bref)	95%	1.718	1.788	1.728	1.787	1.910	1.880	1.765
terminal(Bio/Bref)	5%	1.010	1.096	0.989	1.040	1.177	1.113	1.077
terminal(Bio/Bref)	median	1.420	1.493	1.372	1.436	1.578	1.518	1.503
terminal(Bio/Bref)	95%	2.032	2.071	1.974	2.051	2.193	2.143	2.075
minCommCatch	5%	34.4	183.8	182.3	189.4	180.6	185.5	79.8
minCommCatch	median	188.3	255.7	276.2	281.8	248.9	265.6	197.3
minCommCatch	95%	357.6	327.8	398.3	395.9	313.6	353.5	314.0
avCatch	5%	335.5	324.7	355.4	341.0	302.6	321.3	316.5
avCatch	median	400.1	374.5	406.4	386.7	348.6	366.7	380.5
avCatch	95%	456.0	427.4	447.5	427.2	393.0	403.4	437.8
av5yrCatch	5%	387.8	348.9	407.1	380.9	315.7	347.5	348.1
av5yrCatch	median	452.3	394.7	441.6	400.0	355.9	384.5	412.9
av5yrCatch	95%	466.9	437.5	453.8	426.8	391.2	400.0	462.3
minRecCatch	5%	26.5	29.1	25.9	27.3	31.1	29.3	28.7
minRecCatch	median	31.9	35.0	31.5	33.4	37.4	35.5	34.3
minRecCatch	95%	37.8	41.2	38.8	41.2	43.8	42.6	40.0
avRecCatch	5%	36.5	38.1	35.0	36.5	40.2	38.4	38.4
avRecCatch	median	40.4	42.8	39.8	41.9	45.4	43.6	42.4
avRecCatch	95%	47.5	49.2	47.7	49.2	52.5	51.7	48.7
minCPUE	5%	0.520	0.569	0.499	0.536	0.611	0.575	0.567
minCPUE	median	0.617	0.678	0.605	0.647	0.731	0.692	0.665
minCPUE	95%	0.723	0.787	0.740	0.789	0.845	0.822	0.765
avCPUE	5%	0.746	0.784	0.714	0.749	0.832	0.790	0.792
avCPUE	median	0.813	0.871	0.803	0.849	0.928	0.888	0.858
avCPUE	95%	0.942	0.987	0.951	0.985	1.063	1.038	0.979
%AAV	5%	4.0	7.8	2.6	3.1	6.4	3.3	7.9
%AAV	median	15.5	11.8	8.2	7.4	10.1	8.1	16.7
%AAV	95%	31.6	16.3	14.4	12.9	14.5	13.2	27.9
Mean(Bvulnref/Bmsy)	5%	1.542	1.628	1.486	1.562	1.723	1.647	1.623
Mean(Bvulnref/Bmsy)	median	1.838	1.949	1.810	1.902	2.067	1.989	1.928
Mean(Bvulnref/Bmsy)	95%	2.238	2.346	2.239	2.312	2.488	2.427	2.318
	P<Bref	0.044	0.015	0.055	0.028	0.004	0.012	0.017
	P<Bmin	0.004	0.001	0.005	0.002	0.000	0.000	0.001
	P<Bmsy	0.004	0.001	0.004	0.002	0.000	0.000	0.001
	nchanges	0.604	0.940	0.693	0.602	0.924	0.765	0.785
	P<SSB20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<SSB10%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CPUE>0.6	0.982	0.997	0.969	0.988	1.000	0.998	0.996
	CPUE>0.7	0.858	0.950	0.817	0.897	0.984	0.957	0.945
	CPUE>0.8	0.566	0.762	0.536	0.679	0.885	0.796	0.727
	CPUE>0.9	0.237	0.390	0.217	0.339	0.608	0.466	0.346
	CPUE>1	0.087	0.132	0.076	0.118	0.264	0.186	0.127
	CPUE>1.1	0.034	0.047	0.030	0.042	0.102	0.076	0.047
	CPUE>1.2	0.013	0.016	0.011	0.015	0.038	0.030	0.017

Table B5: MPEs from the qinc robustness trial.

qinc	Indicator	28	29	30	31	32	33	28a
av(Bio/Bref)	5%	1.297	1.380	1.318	1.387	1.486	1.457	1.349
av(Bio/Bref)	median	1.536	1.598	1.563	1.608	1.718	1.698	1.571
av(Bio/Bref)	95%	1.847	1.853	1.860	1.866	1.994	1.977	1.859
terminal(Bio/Bref)	5%	1.081	1.159	1.103	1.168	1.269	1.247	1.134
terminal(Bio/Bref)	median	1.485	1.517	1.493	1.523	1.643	1.631	1.510
terminal(Bio/Bref)	95%	1.992	1.992	1.997	1.997	2.129	2.130	1.992
minCommCatch	5%	254.1	287.7	338.8	343.3	277.2	311.2	238.7
minCommCatch	median	451.3	351.9	444.9	399.9	329.2	376.6	358.8
minCommCatch	95%	466.9	417.3	445.0	400.0	385.2	400.0	466.9
avCatch	5%	441.1	412.4	438.2	414.5	381.7	394.6	423.9
avCatch	median	466.9	448.6	457.2	443.5	410.0	414.9	456.5
avCatch	95%	480.4	482.5	475.6	481.0	442.5	444.3	478.5
av5yrCatch	5%	444.7	386.7	436.9	399.6	347.5	375.3	402.1
av5yrCatch	median	466.9	425.4	449.4	413.4	378.4	398.4	449.5
av5yrCatch	95%	467.0	458.3	458.5	453.5	403.9	408.0	466.9
minRecCatch	5%	29.8	32.7	30.6	32.8	35.8	34.7	31.6
minRecCatch	median	37.2	38.6	38.1	39.1	41.5	41.3	38.0
minRecCatch	95%	43.7	43.9	44.1	44.2	46.0	45.9	43.7
avRecCatch	5%	38.3	41.0	38.8	40.8	43.8	42.6	39.9
avRecCatch	median	43.7	45.2	44.4	45.6	48.6	48.1	44.5
avRecCatch	95%	51.5	51.6	52.1	51.7	55.2	55.0	51.7
minCPUE	5%	0.661	0.730	0.678	0.727	0.786	0.766	0.704
minCPUE	median	0.789	0.828	0.807	0.837	0.881	0.867	0.806
minCPUE	95%	0.929	0.935	0.933	0.944	0.986	0.981	0.929
avCPUE	5%	0.865	0.939	0.879	0.936	1.013	0.983	0.912
avCPUE	median	0.991	1.033	1.011	1.044	1.124	1.110	1.015
avCPUE	95%	1.169	1.171	1.185	1.177	1.270	1.265	1.177
%AAV	5%	0.0	3.2	1.0	2.4	3.5	1.8	0.5
%AAV	median	1.4	6.4	2.1	5.5	5.7	3.8	4.5
%AAV	95%	8.0	10.4	4.7	8.2	8.8	6.2	11.3
Mean(Bvulnref/Bmsy)	5%	1.732	1.843	1.767	1.846	1.992	1.946	1.802
Mean(Bvulnref/Bmsy)	median	2.107	2.181	2.144	2.197	2.346	2.322	2.149
Mean(Bvulnref/Bmsy)	95%	2.566	2.607	2.593	2.626	2.796	2.777	2.584
	P<Bref	0.009	0.002	0.006	0.002	0.001	0.001	0.004
	P<Bmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<Bmsy	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	nchanges	0.211	0.696	0.434	0.397	0.760	0.589	0.403
	P<SSB20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<SSB10%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CPUE>0.6	0.997	1.000	0.998	1.000	1.000	1.000	1.000
	CPUE>0.7	0.959	0.993	0.971	0.991	1.000	0.998	0.984
	CPUE>0.8	0.824	0.914	0.862	0.920	0.984	0.972	0.877
	CPUE>0.9	0.487	0.635	0.548	0.663	0.853	0.817	0.563
	CPUE>1	0.190	0.261	0.218	0.284	0.534	0.483	0.227
	CPUE>1.1	0.061	0.072	0.068	0.078	0.224	0.198	0.071
	CPUE>1.2	0.018	0.017	0.020	0.018	0.065	0.059	0.019

Table B6: MPEs from the hiLFwt robustness trial.

hiLFwt	Indicator	28	29	30	31	32	33	28a
av(Bio/Bref)	5%	1.562	1.697	1.560	1.663	1.821	1.751	1.661
av(Bio/Bref)	median	1.767	1.899	1.793	1.896	2.054	2.002	1.853
av(Bio/Bref)	95%	2.081	2.160	2.109	2.162	2.333	2.303	2.131
terminal(Bio/Bref)	5%	1.281	1.416	1.294	1.385	1.556	1.491	1.372
terminal(Bio/Bref)	median	1.740	1.863	1.755	1.855	2.017	1.977	1.829
terminal(Bio/Bref)	95%	2.399	2.462	2.380	2.452	2.613	2.593	2.459
minCommCatch	5%	153.3	253.4	269.0	278.7	250.7	268.7	178.1
minCommCatch	median	308.3	316.0	375.0	379.3	302.2	337.8	285.0
minCommCatch	95%	466.9	373.4	444.9	400.0	352.6	399.9	386.9
avCatch	5%	405.4	384.4	409.8	392.5	360.1	375.6	386.6
avCatch	median	447.4	421.6	441.9	421.9	391.3	400.9	431.0
avCatch	95%	466.9	456.6	461.8	454.3	420.6	424.8	461.8
av5yrCatch	5%	412.4	368.1	420.8	390.4	335.1	363.0	373.5
av5yrCatch	median	461.0	406.1	444.9	412.4	367.6	390.3	425.6
av5yrCatch	95%	466.9	442.8	453.8	426.8	394.6	404.0	465.1
minRecCatch	5%	32.0	35.8	31.8	34.3	38.8	36.7	34.6
minRecCatch	median	37.3	40.5	38.3	40.7	42.6	41.8	39.2
minRecCatch	95%	43.1	44.2	43.7	44.6	46.3	45.9	43.4
avRecCatch	5%	40.3	43.8	40.4	43.0	47.0	45.2	42.8
avRecCatch	median	44.8	47.9	45.5	48.0	51.8	50.7	46.8
avRecCatch	95%	52.1	53.9	52.9	54.1	58.2	57.6	53.5
minCPUE	5%	0.598	0.676	0.601	0.647	0.736	0.702	0.650
minCPUE	median	0.695	0.770	0.713	0.771	0.828	0.806	0.741
minCPUE	95%	0.817	0.860	0.840	0.874	0.922	0.912	0.828
avCPUE	5%	0.803	0.881	0.800	0.862	0.954	0.910	0.860
avCPUE	median	0.883	0.958	0.902	0.958	1.046	1.021	0.930
avCPUE	95%	1.039	1.069	1.051	1.074	1.173	1.156	1.063
%AAV	5%	0.0	5.3	1.1	2.4	4.3	1.9	3.2
%AAV	median	6.0	9.0	3.3	5.3	7.0	4.2	9.6
%AAV	95%	16.4	13.3	8.5	8.8	10.7	7.9	18.2
Mean(Bvulnref/Bmsy)	5%	1.492	1.619	1.489	1.596	1.750	1.681	1.590
Mean(Bvulnref/Bmsy)	median	1.756	1.882	1.782	1.880	2.035	1.988	1.841
Mean(Bvulnref/Bmsy)	95%	2.090	2.175	2.126	2.187	2.355	2.319	2.153
	P<Bref	0.001	0.000	0.001	0.000	0.000	0.000	0.000
	P<Bmin	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<Bmsy	0.001	0.000	0.001	0.000	0.000	0.000	0.000
	nchanges	0.385	0.821	0.508	0.435	0.810	0.605	0.589
	P<SSB20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	P<SSB10%	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CPUE>0.6	0.999	1.000	0.999	1.000	1.000	1.000	1.000
	CPUE>0.7	0.974	0.999	0.975	0.994	1.000	0.999	0.995
	CPUE>0.8	0.811	0.959	0.844	0.941	0.995	0.982	0.920
	CPUE>0.9	0.453	0.711	0.515	0.705	0.899	0.831	0.616
	CPUE>1	0.187	0.372	0.224	0.374	0.655	0.568	0.299
	CPUE>1.1	0.071	0.127	0.082	0.133	0.363	0.293	0.109
	CPUE>1.2	0.025	0.035	0.027	0.037	0.136	0.110	0.035

Glossary

This glossary is intended to make the rock lobster stock assessment 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 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 catches from various sectors within the TAC/TACC; 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 a 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 variability of the parameter estimates is 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 kg 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.

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, *viz.* 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): 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, fishermen 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;

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 of Agriculture and Forestry).

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.

***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 MFish, commercial, customary and recreational sectors, that provides rock lobster management advice to the Minister of Fisheries.

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 clever comparison of the actual and theoretical distributions of normalised residuals by plotting the observed quantiles in an ingenious 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: a group convened by MFish to discuss stock assessment alternatives and to act as peer-reviewers; comprises MFish, 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) 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 of Fisheries 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; $Z = F + M$.