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CRA 9 management procedure evaluations

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Paul A. Breen

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EXECUTIVE SUMMARY

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This report addresses part of Objective 5 of Ministry for Primary Industries contract CRA2012-01A, held by the New Zealand Rock Lobster Industry Council, and describes development of a management procedure for CRA 9. Catch and CPUE data from 1963 in CRA 9 were used in simple modelling using simple assumptions. This procedure was used instead of the length-based lobster model because of time limitations.

Commercial, recreational, customary and illegal catches were estimated or assumed. Commercial catches have been well reported. Recreational catch was assumed to be proportional to spring-summer CPUE; an estimate for the 2011 fishing year from a recent nation-wide recreational fishing survey was used to construct the whole vector. Customary and illegal catches are poorly known, and assumptions were based on advice from MPI. Annual CPUE was standardised using the same procedures used for recent stock assessments.

Simple production models, implemented in AD Model Builder, were fitted to the data, then posterior distributions of estimated parameters were obtained from Markov chain – Monte Carlo simulations. The base case model was stabilised by a prior on the intrinsic rate of increase, which was developed from simple simulations using growth data from tag-recaptures.

The fitted models were used as the basis for operating models, with added stochastic variation in annual production and stochastic CPUE observation error based on the patterns observed in the fitting. A family of harvest control rules was defined, a standard set of indicators was defined, and simple explorations were made to explore the productivity characteristics of the model.

As well as the base case model, five robustness trials used alternative operating models: these involved an alternative model fitted without a prior on the intrinsic rate of increase, two trials with alternative recreational catch assumptions, and models with increased CPUE observation error and decreased annual production.

More than 1100 plateau harvest control rules were explored; some rules were screened out that failed to meet simple criteria based on safety indicators. From a set of 112 candidate rules based on further screening, stakeholders chose a small set of rules that were presented to the National Rock Lobster Management Group, who made final rule choices.

Appendices show CRA 9 length frequencies from voluntary logbook catch sampling, an analysis of retention by sex and size over time based on the logbook data, a description of the tag-recapture data, and a late error discovered by MPI in the recreational catch estimates.

1. INTRODUCTION

This work was conducted under Objective 5 of Ministry for Primary Industries (MPI) contract CRA2012-01A, held by the New Zealand Rock Lobster Industry Council Ltd (NZ RLIC):

> *Objective 5. Development of management procedures.*
> *To evaluate new management procedures for rock lobster fisheries.*

The National Rock Lobster Management Group (NRLMG) determined that this Objective should be addressed partly by developing a new management procedure for CRA 2 (Starr et al. 2014) and partly by a new management procedure for CRA 9, the Westland –Taranaki stock.

The CRA 9 fishery for red rock lobsters (*Jasus edwardsii*) is the least studied of the nine New Zealand rock lobster fisheries. CRA 9 extends from Bruce Bay in Westland to the Kaipara Harbour in west coast Northland (see Figure 1), but has a TACC of just over 47 t, the smallest of any rock lobster QMA. Commercial lobster fishing in CRA 9 is limited to the north-west coast of the South Island and the Taranaki coastline.

No formal stock assessment has been done for CRA 9. No TAC has been set for this fishery and the current TACC of 47 t, set in 1992 after two reductions from the original 54.66 t set in 1990, has remained unchanged. The TACC has been fully caught since 1992. CPUE increased strongly from 2000 to 2006, declined and then increased strongly again from 2008 to 2012, with 2012[1] having the highest CPUE recorded.

There are no reliable estimates of customary or illegal catches for the CRA 9 fishery but there are uncertain estimates of the recreational catch. There are 23 quota share owners, but in the 2012–13 fishing year only five commercial vessels reported more than 1 t of CRA 9 landings (Paul Starr, unpublished data). Value of the landed catch was estimated from average port price to be $2.6 million (NRLMG 2010).

This study addresses the possibility of a management procedure for CRA 9. Management procedures are extensively simulated-tested decision rules: see Johnston & Butterworth (2005) for discussion of a management procedure used to manage rock lobsters in South Africa. Management procedures are now a major part of New Zealand rock lobster management (Bentley et al. 2003b; Breen et al. 2009b). They have been used to rebuild the depleted CRA 8 stock in New Zealand and to manage the volatile CRA 7 (Starr et al. 1997; Bentley et al. 2003a; Breen et al. 2008; Haist et al. 2013); a voluntary management procedure was used to govern ACE shelving in CRA 4 to rebuild a badly depleted stock (Breen et al. 2009c) and was revised by Breen et al. (2012); a management procedure was adopted for CRA 5 for the 2012–13 season, after use of a voluntary management procedure designed to maintain high abundance (Breen 2009a); a management procedure was adopted for CRA 3 in 2010 (see Breen et al. 2009a); management procedures were developed for CRA 2 in 2013 (Starr et al. 2014). Management procedures for CRA 6 were explored in 2009 (Breen 2009b).

This study continues similar previous work (Breen 2011a; Breen unpublished). A report was made to the Rock Lobster Fishery Assessment Working Group (RLFAWG) in 2012, but the standardised CPUE was later found to have serious problems. A revised approach to collating data for CPUE (Paul Starr, unpublished data) was accepted by the RLFAWG in June 2013 and its results were used for this project.

The modelling approach is similar to that of Breen (2009a; 2009b; 2011a, 2011b). Productivity of the stock was first explored using a variation of the method described by Hilborn (2001) (see also Walters et al. 2008). Next, a simple stock assessment was performed with a surplus-production model. Breen (2011b) explored the utility of this approach with a comparison in CRA 5, where a recent stock assessment had been done with the age-structured model. He concluded that the simple model performed adequately for developing management procedures. The RLFAWG, on 6 October 2011, concluded (MFish unpublished) that (errors corrected):

> *Despite the numerous differences between the two operating models, over the likely ranges of future catch (particularly over the range 400 t - 600 t) and associated CPUE, the WG noted that performance of the decision rules under the two models was very similar. Only when the decision rule / fishery was being driven hard (high catches, low CPUEs) did the rule performance under the two operating models differ substantially. In some performance measures (min Biomass, mean Biomass) the surplus production model was more conservative, but the two models were particularly similar in terms of the distribution of minimum and mean catches and CPUE.*

[1] The lobster fishing year runs from 1 April through 31 March, and the established convention is to name the fishing year after the April–December portion; *viz.* 2011–12 is named 2011.

The WG concluded that these results gave confidence that a production model-based operating model could reliably be used to conduct MPE evaluations of alternative decision rules for the CRA 9 fishery.

A family of harvest control rules was defined. Forward projections were made with various harvest control rules, and a set of fishery indicators was defined for use in evaluating rules. Preliminary explorations were made to explore the productivity of the operating model. Then a series of evaluations were made to identify suitable harvest control rules that could be used in a CRA 9 management procedure. These evaluations were made with the base case and five robustness trial models.

For explanations of technical terms used here, refer to the Glossary of Haist et al. (2013).

2. CRA 9 DATA

Data were compiled in mid-2013 for 1963–2012. The earliest year with any abundance index was 1963, and the last year of data available for this work was 2012.

2.1 Catch data

CRA 9 commercial catch data were taken from the CRACE database (Bentley et al. 2005). These come from Annala & King (1983), Annala & Esterman (1986), annual FSU reports by Brian Sanders (e.g. Sanders 1983), Booth et al. (1994) and the FSU and QMR/MHR databases. Commercial catches are shown in Table 1 and Figure 2. Commercial catch data were not collected during 1974–78, and were interpolated. Commercial catches for 1988 and 1989 were suspiciously lower than the adjacent catches (26 and 27 t respectively): these were years in which the Ministry of Agriculture and Fisheries[2] changed its data collection procedures and lost data in the process. Catches for these two years were also interpolated.

Non-commercial catches are poorly known. Little is known of customary catch apart from permit information supplied to MPI. Alicia McKinnon (MPI, pers. comm. 5 June 2013) advised:

MPI recommends that 1 tonne is used as the customary catch estimate in the CRA9 MPEs. Information we have suggests that very little harvesting occurs under the customary regulations along the CRA9 coastline. However, a key part of the fishery – the Taranaki area – is covered only by regulation 27A reporting. There is no requirement to provide this information to MPI and we don't have a feel for what is going on from a customary perspective there.

The RLFAWG agreed to assume 1 t for the whole time series.

Recent catches reported under Section 111 of the Fisheries Act 1996, allowing commercial fishers to take a recreational bag limit, were extracted from the CRACE database (Bentley et al. 2005). These had a maximum of 2.26 t (Paul Starr, unpublished data), and this value was applied to all years (Table 1).

Recreational catches were estimated for CRA 9 as part of a recent survey conducted for MPI in the period October 2011 through October 2012 (National Research Bureau (NRB), unpublished data), and their estimate was considered to be the best available information. The estimate for 2011 was 25.995 t, using a mean weight of 1.156 kg (Bruce Hartill, NIWA, unpublished data). The RLFAWG agreed to assume that recreational catch has been proportional to CPUE in spring-summer, and the base case recreational catch vector was calculated. Catch in 1945 was assumed to be 20% of 1979 catch, and years from 1946 through 1978 were interpolated linearly.

Uncertainty in recreational catch is the largest component of uncertainty in total catch; to address this, two alternative catch vectors were calculated. In the first, recreational catch before addition of the

[2] Now part of the Ministry for Primary Industries.

s. 111 catch was simply halved. In the second, the NRB (unpublished) estimate of recent numbers caught was multiplied by an alternative mean weight of 1.92 kg, which was based on voluntary logbook sampling (see Appendix A). These alternative series are shown in Table 1 and in Figure 3.

After this work had been completed and reported to the NRLMG, MPI became aware of an error made by NRB in assigning catch to CRA 9; this is documented in Appendix D. For three reasons, the RLFAWG agreed to let the work stand as reported:

- the effect of the error on total catch was small
- there was no time, in the middle of the CRA 2 assessment workshop, to re-work the project with the revised total catch vectors
- the revised CRA 9 recreational catch was greater than the low-catch sensitivity trial.

Illegal catches were estimated by MFish Compliance for 1990–96 (Table 1). The following algorithm was used by Paul Starr (see Starr et al. 2013) to prepare the series of illegal catches (Table 1 and Figure 2):

1. Starting with estimates of export discrepancies for all of New Zealand for 1974–80 (John McKoy, NIWA, unpublished data), the CRA 9 illegal catches for these seven years were estimated from the ratio of the reported commercial catch in CRA 9 to the total New Zealand reported commercial catch for the same years.
2. The average ratio in CRA 9 of the export discrepancy catch to reported commercial catch was calculated for the period 1974–80 and used to generate an illegal catch estimate for years with no data (1945–73 and 1981–89) by multiplying the reported catch by the average ratio.
3. Beginning with 1990, illegal catch was based on MFish Compliance estimates (Table 1). For years after 1990 without Compliance estimates, the level of illegal catch was interpolated (Table 1). For years from 2001, 1 t was assumed as agreed by the RLFAWG.

Annual total catch is the sum of the commercial, s. 111, recreational, customary and illegal estimates. In most recent stock assessments (e.g. Starr et al. 2013), the catch is divided into two seasons, but for this work an annual time step was considered adequate, and avoids having to estimate seasonal catchability. In stock assessments that use the length-based model of Haist et al. (2009) the catch is also divided into two components, depending on whether the MLS was respected, but this is not possible in the simple biomass-based model used here.

2.2 CPUE data

Monthly catch and effort (days fishing) data from 1963–73 were summarised by Annala & King (1983) and used to calculate unstandardised catch per day for each calendar year from 1963 to 1973. Paul Starr (pers. comm.) extracted the CRA 9 values from the CRACE database (Table 2).

CPUE was available as standardised kg per pot-lift for 1979–2012 (Paul Starr, pers. comm.). Methodology was described by Starr (2013). Methods of grooming were as described by Bentley et al. (2005), and standardisation used the F2 algorithm (Starr 2013), after much exploratory work in early 2013 (Paul Starr, Starrfish, unpublished data).

The relatively new F2 algorithm was developed to address a disconnection between catch and effort. Lobsters are reported when they are put into holding pots or onshore storage ponds, but when they are "landed" to a licences receiver they are given the same code as lobsters that come directly from pots. It also addresses high-grading, which is the legal return of lobsters to the sea, usually done in the hope of replacing lower-priced fish with higher-priced, depending on grade price differentials. Finally, it addresses the catch of recreational fish by commercial fishers under section 111.

Vessel numbers have declined over time in this and other New Zealand rock lobster fisheries, and the CPUE analysis was limited to just five vessels that reported more than 1 t of lobster landings in 2012. These five vessels are spread out over a large area, with the potential to create or exploit local

abundance patterns. The limited data result in sensitivity of CPUE indices to shifts in effort and local catchability that may not be abundance-related.

CPUE estimates are shown in Table 2 and in Figure 4. From 1979, catch per pot showed a minimum of 0.75 in 1985 and a maximum of 2.98 in 2012.

2.3 Length frequency and tag-recapture data

These data were not used directly by the modelling, but are part of the characterisation of CRA 9. Length frequency data are collected by a voluntary logbook program in CRA 9. They show that large fish are relatively abundant and that mean sizes of legal fish have been increasing (Appendix A).

Participants in the logbook program record whether a fish is retained, and this information was used to explore patterns of retention (or conversely, legal high-grading) in CRA 9. Mostly males are high-graded; the rate of high-grading has increased in recent years; the weight returned to the sea was nearly half the weight that could have been retained, i.e. half the legal catch, in 2011 (Appendix B).

Tag-recapture data from CRA 9 are sparse, but they are described in Appendix C. They were used to explore a prior probability distribution for the intrinsic rate of increase (see below).

3. OBSERVED PRODUCTION

The catch and CPUE estimates in Table 1 and Table 2 can be used to estimate production if catchability is assumed. Biomass can be estimated as:

$$B_t = \frac{I_t}{q} \quad (1)$$

where B_t is biomass in year t, I_t is CPUE in year t and q is assumed catchability. Once biomass is estimated, annual production is the change in biomass plus the catch:

$$P_t = B_{t+1} - B_t + C_t \quad (2)$$

where C_t is the total catch in year t. This method is a variant of that described by Hilborn (2001), and was used to estimate production patterns in CRA 5 (Breen 2009a; 2011b) and CRA 6 (Breen 2009b).

Using estimated catchability from the base case observation error surplus production model described below, biomass and production estimates for CRA 9 are shown in Figure 5 and Figure 6. Annual production plotted against biomass (Figure 7) shows high variability in the biomass range that comprised most of the period; there is one large negative production estimate. Exploitation rate (assumed catch divided by estimated biomass) (Figure 8) peaked at 38% in 1986 and the minimum after 1964 was 8.6% in 2006.

Biomass, production and exploitation rates estimated by this method are all sensitive to the assumed catchability; the trends are much less sensitive. The exploitation rate trajectory (Figure 8) seems reasonable when the current length structure (Appendix A) is considered.

4. SURPLUS PRODUCTION MODEL

A simple surplus-production model was fitted, which predicts annual production as a function of biomass:

$$\hat{P}_t = rB_t\left(1-\left(\frac{B_t}{K}\right)^p\right) \quad (3)$$

where *r*, *p* and *K* are parameters of the model: they are the intrinsic rate of increase, shape and carrying capacity respectively. *Bmsy* is given by:

$$Bmsy = K\left(\frac{1}{1+p}\right)^{\frac{1}{p}} \quad (4)$$

and *MSY* is obtained by substituting (4) into (3).

The model was fitted by using both an observation error time series approach and a process error approach (see Hilborn & Walters 1992). In the observation error approach, the 1963 biomass was an estimated parameter, *Binit*. For both fits, subsequent biomass was predicted by this rearrangement of (2):

$$B_{t+1} = B_t + \hat{P}_t - C_t \quad (5)$$

This model was fitted by predicting CPUE with an estimated catchability:

$$\hat{I}_{t,day} = q_{day}B_t \quad \text{for catch per day, 1963–73} \quad (6a)$$

$$\hat{I}_{t,pot} = q_{pot}B_t \quad \text{for catch per pot, 1979–2012} \quad (6b)$$

where q_{day} is the catchability for the 1963–73 series and q_{pot} is catchability for 1979–2012.

Predicted and observed CPUE values in the earlier series were compared with robust log-normal likelihood (Bull et al. 2012) for each year:

$$-LL_t = \ln\left(\sigma_{day}\right) - \ln\left(\exp\left(-0.5\left(\frac{\ln\left(I_{t,day}/\hat{I}_{t,day}\right)}{\sigma_{day}} + 0.5\ \sigma_{day}\right)^2\right) + 0.01\right) \quad (7)$$

where σ_{day} was an estimated parameter; these are summed across all years with pot/day data. Normalised residuals were:

$$residual_{t,day} = \frac{\ln\left(I_{t,day}/\hat{I}_{t,day}\right)}{\sigma_{day}} + 0.5_t\sigma_{day} \quad (8)$$

The likelihood and residual equations for the later series, with catch per pot, were analogous. Apart from estimating the variance components separately for the two series, the two abundance index data sets were given equal weight.

For the process error approach, CPUE was predicted from the previous year's CPUE, model parameters and catch. The previous year's biomass was calculated from (1), predicted production from (3), then

$$\hat{I}_{t,day} = q_{day}\left(B_{t-1} + \hat{P}_{t-1} - C_{t-1}\right) \quad (9)$$

This fitting approach has one fewer parameter (there is no need for *Binit)*, but fits to two fewer data: without the preceding year's CPUE, the first CPUE datum in each of the two series cannot have a predicted value to compare with the observed.

For both approaches, biomass was prevented from going below zero with the differentiable ADMB function *posfun*, which has an associated penalty that forces the minimiser to find solutions with positive biomass. The final solutions had zero penalty values.

Estimated parameters were assigned uniform priors with wide bounds (Table 3) except for *r*. Preliminary McMCs had wide variation in this parameter, with associated variation in derived biomass parameters. An informed prior for *r* was developed using tag-recapture data and the prior on natural mortality rate, *M*, used in other rock lobster assessments. When using simple models, there are often external data, not used by the model, that contain information about the likely values of model parameters and enable informative priors to be used (e.g. Carruthers & McAllister 2011).

The model was implemented in both Excel™ and AD Model Builder. Implementing the model in both platforms gave a check against implementation error and allowed quick exploration of the fits for setting up initial values.

4.1 Prior on the intrinsic rate of increase

The prior on *r* was constructed with a very simple model that used growth estimates from tag-recapture data and an established prior on natural mortality rate, *M*.

Tag-recapture data from CRA 9 are described in Appendix C. Growth parameters were estimated from the tag-recapture data using the paua growth model of Breen et al. (2003). Ignoring the sex superscripts, the model was:

$$\Delta^{TW} = \Delta^{t} g^{\alpha}\left[\left(g^{\beta}/g^{\alpha}\right)^{V}\right] \quad (10)$$

where Δ^{TW} is the predicted increment in tail width (TW), Δ^{t} is the elapsed time in years, g^{α} is the growth at tail width (TW) α, g^{β} is the growth at TW β, and *V* is given by:

$$V = \frac{TW_t}{(\beta - \alpha)} - \frac{1}{(\beta/\alpha) - 1} \quad (11)$$

Values of 50 and 80 mm were used for α and β respectively. The predicted increment was limited to positive values with *posfun*. This model was used, instead of the more complex model of Haist et al. (2009), because of its simpler structure with no shape parameter, which seemed appropriate given the sparse data. Both the Haist et al. (2009) and this model are continuous growth models: they do not attempt to account for the step-wise growth caused by moulting.

Fitting to observed increments in the tag-recapture data used robust normal likelihood, and was done with a purpose-built ADMB program after verifying its estimation ability with simulated test data.

This simple model also "estimated" *M*, which was assigned the same prior as used in recent lobster stock assessments (e.g. Haist et al. 2013): a lognormal prior with a mean of 0.12 and standard deviation 0.35, developed originally based on a literature search. There is no information on *M* in the growth data, so the posterior distribution of *M* was nearly the same as the prior. The only variance term estimated was a growth CV common to both sexes. The growth CV determines the standard deviation of the expected growth increment, which was truncated to be greater than 0.1 after experiment.

The joint posterior distributions of the growth parameters and *M* were estimated from five million McMC simulations, with 5000 samples saved, and are summarised in Table 4. Distributions of growth parameters were wide, as was to be expected from so few data.

The output of this procedure was 5000 samples of the posterior distributions of growth parameters and *M*. These were used to estimate *r* by setting up a simple length-based population of lobsters, males and females separately, with 2-mm size bins from 31 to 111 mm TW. In year 1, all bins were empty except for the first bin for each sex, which received recruitment of 10 000. The model constructed a growth transition matrix for each sex from the growth parameters. For each sex, the vector of numbers in the next year was determined from the vector of numbers in the previous year:

$$\mathbf{N_{t+1}} = \mathbf{N_t}\mathbf{G} \quad (12)$$

where $\mathbf{N_t}$ is the vector of numbers in year *t* after applying natural mortality, e^{-M}, and $\mathbf{G}$ is the growth transition matrix. For each sex, the model calculated recruited biomass for each year, based on the minimum legal size (MLS) of 54 mm TW for males and 60 mm for females. Parameters from the length weight relation (Nokome Bentley, Trophia, unpublished data) are shown in Table 5.

The 50-year trajectory of recruited biomass from the first parameter vector is shown in Figure 9. For all 5000 parameter vectors, the model made a 3-year trajectory of biomass, and calculated *r* as the increase between years 2 and 3:

$$r = \frac{B_3}{B_2} - 1 \quad (13)$$

The posterior distribution of *r* is summarised in Table 4 and is shown, except for a handful of very high values, in Figure 10. For the surplus production model, the prior on *r* had the same mean as this distribution but was made deliberately broad to reflect uncertainty associated with this procedure:

- very sparse tag-recapture data
- uncertain length-weight relations
- uncertain *M*
- no consideration of density-dependent effects on growth or mortality
- uncertainty associated with this approach.

The assumed prior used in the fitting is shown in Table 3.

4.2 Parameter estimation - observation error time series fit

From the observation error time series approach, fits between observed and predicted CPUE from the mode of the joint posterior distribution (MPD) are shown in Figure 11 and Figure 12. The fit to kg/day was good, at least after the first four years, and the fit to kg/pot was good but had trouble tracking the most recent year. The estimated catchability for kg/day was 23 times that for kg/pot.

"Observed" production (from the simple procedure described above) and predicted production are compared as functions of biomass in Figure 13: remember that the model did not fit to production.

The plot suggests that production does not vary with biomass over the range estimated from 1963–2011, and that variability in production is high.

An McMC chain of 10 million simulations was started at the MPD, and 2500 samples were saved. The posterior distributions of estimated and derived parameters are summarised in Table 6. Diagnostic plots of major estimated and derived parameters are shown in Figure 14 through Figure 20. The traces for *K*, *r* and *p* appeared well behaved and converged. *Binit* was not well behaved, but derived parameters such as 2012 biomass, *MSY* and *Bmsy* appeared to be converged. The posterior distribution of *r* was shifted slightly left of the prior (Figure 21).

Correlations among estimated parameters in the McMC (Table 7) were highly negative between *r* and *p*, and were high among some estimated parameters and derived parameters: for instance, current biomass, *MSY* and *CSP* were highly correlated with *K*.

This work was not a stock assessment, although it followed the general pattern of stock assessments, using a much simplified model. Current (2012) biomass was estimated to be well above *Bmin* (Table 6), at about half of *K* (5% to 95% range 54% to 66%) and 56% above *Bmsy* (40% to 70%). *MSY* was estimated at 102 t (98 to 108 t; this includes all catches), which is similar to the average estimated total catch of 103 t from 1963 through 2012. Current surplus production (CSP) was estimated as 86 t (80 t to 96 t); it was lower than *MSY* because estimated current biomass was higher than *Bmsy*.

According to this model, 2012 biomass was above *Bmsy* with 100% probability. Both the *MSY* of 102 t and the current surplus production (*CSP*) of 86 t were near the estimated current total catch of 95 t. The model estimated that recent exploitation rate was low: MPD 12% in 2012, compared with a median equilibrium exploitation rate at *Bmsy* of 19%.

A version of the "snail trail" plot used in recent New Zealand stock assessments is shown in Figure 22. The phase space is defined by biomass relative to *Bmsy* on the x-axis and fishing intensity relative to *Umsy* on the y-axis. The stock in 1967 was well above *Bmsy* and fishing was near the rate associated with *MSY*; in 1975 the exploitation rate exceeded the optimum, and until 1990 the stock decreased. Maximum fishing pressure occurred in 1987 and stock reached its lowest value in 1989. After CRA 9 was introduced into the QMS, the stock increased and fishing pressure decreased: for 19 years fishing pressure has been less than the rate associated with *Bmsy*, and for 14 years median biomass has been above *Bmsy*.

4.3 Parameter estimation - process error time series fit

CPUE was fitted well in the process error fit (Figure 23), and the function value was similar to that from the observation error fit. The posterior for K was not good (Figure 24), with some extremely large values and with dubious convergence. This gave a median K that was much larger than in the observation error fit (Table 8). The parameter *r* was well-behaved (Figure 25). Other traces were mixed: some appeared converged but *MSY* was very poor (Figure 26). Most biomass values had medians far higher than in the observation error model.

This set of estimates would not be accepted in a stock assessment. It had been intended to use the process error fit as a robustness trial, but it was too unstable for that. The observation error fit was clearly more stable and was chosen as the base case.

5. MANAGEMENT PROCEDURE EVALUATIONS

5.1 Harvest control rules

Three harvest control rule families were used in this study. The first two were used only for exploratory runs, and the third was used in actual evaluations. Harvest control rules determined the projected TACC.

The rule 1 family had a constant TACC, which could be zero, and non-commercial fishing occurred in addition to commercial (see below).

The rule 2 family used a constant multiplier on CPUE to obtain TACC, using CPUE from the current (not previous, as in real-life rules) projected year, and using the predicted CPUE before observation error was applied; thus rule 2 used perfect information about the stock. Non-commercial fishing occurred in addition to the commercial catch (see below).

The rule 4 family[3] is similar to the "step rule" adopted in 2012 for CRA 5 (see Haist et al. 2011) and evaluated in 2012 for CRA 2 (Starr et al. 2014). This generates an annual TACC based on observed CPUE in the preceding year.

The rule has four major sections (see Figure 27):

- a phase with very low CPUE (less than *par2*) where the fishery is shut down; a phase that should seldom or never be reached
- a "rebuilding phase" when CPUE is between *par2* and *par3*; in this phase, a change in CPUE results in a change in TACC
- a plateau where CPUE is between *par3* and par4, where the TACC does not change as CPUE changes within this range; plateau height is determined by *par6*; the plateau can be wide or narrow, and is not present if *par3* equals *par4*
- a series of steps when CPUE is higher than *par4*, where the step width is determined by *par5* and the step height (a percentage of the existing TACC) by *par7*.

This is a summary of the rule 4 parameters:

par1 rule type, equals 4
par2 the CPUE at or below which TACC is 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 steps
par6 the TACC on the first plateau
par7 the proportion by which TACC increases at a step
par8 minimum change threshold

The rule is described by:

(14) $$TACC_{t+1} = 0 \qquad \text{for } I_t \le par2$$

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

(16) $$TACC_{t+1} = par6 \qquad \text{for } par3 < I_t \le par4$$

(17) $$TACC_{t+1} = par6\left(\left(1 + par7\right)^{\text{int}\left(\left(I_t - par4\right)/\,par5\right)+1}\right) \qquad \text{for } I_t > par4$$

[3] "Rule 3" was a different rule evaluated in the previous CRA 9 study (Breen 2011a), not used here.

where $TACC_{t+1}$ is the TACC (tonnes) in year t+1 and I_t is offset-year CPUE (kg/potlift) in year t.

The rule parameters cannot be negative except for *par2*; *par5* and *par6* must be greater than zero; *par2, par 3* and *par4* must follow this rule:

(18) $par2 <= par3 <= par4$

Additional rule parameters can buffer the operation of the rule, and in previous work the NZ RLIC stock assessment team has explored minimum and maximum TACC changes, a "latent year" sub-rule that prevents TACC change in two successive years, and an asymmetric latent year sub-rule that operates differently when CPUE is increasing or decreasing. The plateau rule, if tuned correctly, should be inherently more stable than rules that generate a TACC change every year. Buffering reduces the responsiveness of a harvest control rule and thus involves a tradeoff between safety and stability.

In this study, the only buffering was a minimum TACC change, defined as *par8*. It was varied in exploratory production runs and then was fixed at 5% for all rules tested, which meant that the TACC could be changed by only 5% or less, except of course when CPUE was above the main plateau and *par7* was set at 5% or less.

5.2 Projection model

Projections were made by running the surplus production dynamics forward (equation (5)). One run was made from each of the 2500 samples from the joint posterior distribution of parameters.

Projection catches were as follows:

- Commercial catch: the current TACC of 47 t was used for 2013, and in subsequent years the TACC was determined by the harvest control rule being tested.
- Recreational catch: for each year from 1979–2012 for each posterior sample, the recreational exploitation rate was calculated as recreational catch (Table 2) divided by model biomass, and the mean was obtained. Projected recreational catch was then determined as the product of this recreational exploitation rate and model biomass for each projection year.
- Illegal catch: was assumed to be 1 t.
- Customary catch: was assumed to be 1 t.
- Section 111 catch: was assumed to be 2.2635 t.

CPUE used as input to the harvest control rule was determined from model biomass times estimated catchability. Stochastic observation error was added based on the CPUE residuals in each run. The CPUE observation error deviations were:

(19) $$Idev_t = \mu + \rho^{obs} Idev_{t-1} + \sqrt{1-\left(\rho^{obs}\right)^2}\left(\sigma^{Idev}\varepsilon_t\right)$$

where ρ^{obs} is the amount of autocorrelation between successive years, σ^{Idev} is the standard deviation of CPUE residuals in log space in the run, $\varepsilon \cong \mathrm{N}(0,1)$ and μ is the mean of CPUE residuals in log space in the run:

(20) $$\mu = \frac{\sum_{t=1979}^{t=2012} \ln\left(I_t^{obs} / I_t^{pred}\right)}{34}$$

The value of ρ^{obs} was set to 0.364, the median of autocorrelations in CPUE residuals in the McMC.

The projected CPUE, $\hat{I}_y^{proj}$, was:

(21) $$\hat{I}_t^{proj} = q_{t,pot} B_t \exp\left(Idev_t\right)$$

The projection dynamics incorporated stochastic production deviations. In the pre-projection years, these were calculated as:

(22) $$Pdev_t = \hat{P}_t - P_t$$

where $\hat{P}_t$ is production estimated by the surplus production model and P_t is estimated by equation (2). The production deviations from the MPD fit are shown in Figure 28.

Preliminary trials showed that projections were sensitive to both the years chosen for projection and to the inclusion of autocorrelation. The 2011 production deviation is the largest of the series by far, caused by the very high 2012 CPUE, and is somewhat suspect, while deviations before 1992 appear to be smaller in scale than those from 1992 onwards. Based on that pattern, production deviations from 1992–2010 were used as the basis for projections.

In the McMC results, the median autocorrelation in these deviations was -0.31; this was used as the value for ρ^{prod} when generating production deviations:

(23) $$Pdev_t = \mu^{Pdev} + \rho^{prod} Pdev_{t-1} + \sqrt{1-\left(\rho^{prod}\right)^2}\left(\sigma^{Pdev}\varepsilon_t\right)$$

where the mean and standard deviation of deviations, μ^{Pdev} and σ^{Pdev}, were based on the 1992–2010 deviations. The 2010 deviation was used to project the 2011 deviation to begin the projection series. Projected biomass was:

(24) $$B_{t+1}^{proj} = B_t^{proj} + rB_t^{proj}\left(1-\left(\frac{B_t^{proj}}{K}\right)^p\right) + Pdev_t - C_t^{proj}$$

Negative production deviations can exceed biomass, which can result in negative model biomass, so low model biomass was arbitrarily truncated at 1 t. When the total catch exceeded 75% of biomass, it was truncated to 75% of biomass, and each catch component was reduced proportionally.

Runs were made for fifty years, through 2064. For each set of runs for a harvest control rule, projections were made from each of the 2500 samples from the joint posterior distribution that had been obtained from the McMC simulations.

5.3 Indicators

Indicators were defined for risk, yield, abundance, and stability of the catch limit. Indicators from each run were as follows:

- minBio: the minimum of biomass during the run from 2014–2064
- meanBio: the average biomass during the run
- minTACC: the minimum TACC during the run
- minComm: the minimum commercial catch during the run
- meanComm: the average commercial catch during the run
- minRec: the minimum recreational catch during the run

- meanRec: the average recreational catch during the run
- meanTotal: the average total catch during the run
- minCPUE: minimum of CPUE during the run
- meanCPUE: the average CPUE during the run
- AAVH: the average annual change in TACC
- %<*Bmin*: the percentage of years in which biomass was less than *Bmin*
- %<*Bmsy*: the percentage of years in which biomass was less than *Bmsy*
- %<20*K*: the percentage of years in which biomass was less than 20% *K*
- %collapse: the percentage of runs in which at some stage the biomass became less than 1 t
- TACCnow: the TACC that would be set by the rule based on the standardised offset-year CPUE for 2012–13, which was 3.1409 kg/pot (Paul Starr, in prep.).

(Offset-year is the year from October through September. It is used to drive management procedures because it can be calculated in November, using an additional six months of recent data compared with the fishing year. See the Discussion.)

AAVH was calculated as:

$$AAVH = \sum_{y=2014}^{y=2063} \frac{\left|TACC_y - TACC_{y-1}\right|}{0.5\left(TACC_y + TACC_{y-1}\right)} \quad (25)$$

Indicators were written from each run, and were summarised for a set of 2500 runs by the median of the posterior distribution except for the four percentage indicators, which were all based on the sum from each set of runs; TACCnow had only a single value for each rule.

5.4 Preliminary explorations

Sets of runs were made with rule 1, with various constant TACCs between zero and 145 t, and rule 2 with multipliers that gave TACCs from zero to 145 t at CPUE = 1.0. Summaries are shown in Table 9 for rule 1 and Table 10 for rule 2.

The maximum of average[4] total catch was 101.4 t, obtained under rule 2 with a multiplier of 67 t per kg/potlift. This was associated with average CPUE of 1.19 kg/potlift and average biomass of 479 t. Under rule 1, the maximum average total catch was less: 98.5 t, obtained with a constant TACC of 75 t and associated with average CPUE of 1.43 kg/potlift and average biomass of 574 t.

These values, if taken as indicators of *MSY* and *Bmsy*, are comparable with results from the surplus production model's deterministic MPD and McMC results, as shown in the text table below. For the rule 1 and rule 2 projections, the exploitation rate at *Bmsy*, *Umsy*, was calculated by simply dividing the median *MSY* by the median *Bmsy*.

	MSY (t)	*Bmsy* (t)	*Umsy*
Base case MPD	100.9	500.0	20.2%
McMC median	101.8	513.2	19.8%
rule1	98.5	574	17.2%
rule 2	100.4	479	21.2%

For these exploratory rules, some indicators are plotted against the median total catch in Figure 29. Near *MSY*, rule 2 gave a slightly higher total catch for a given level of average biomass or CPUE. The centre left panel of Figure 29 shows that catch increased linearly with fixed TACC up to a TACC of 95 t, then decreased as TACC increased, whereas minimum TACC decreased at high catch (low

[4] For catch and CPUE indicators, the mean across all projection years was calculated for each run, and the posterior distribution of means was summarised by the median; this is described here as the "average".

abundance) under rule 2. Mean commercial catch increased in proportion with total catch, but at high fishing intensity the proportion of commercial catch in the total catch increased because recreational catch decreased as abundance decreased.

Figure 29 also shows some safety indicators plotted against mean total catch: in each case rule 2 showed higher safety at high catches than rule 1. This is also shown in the table below, where the values are the highest average total catch that remains below the threshold shown for each indicator. For rule 2 the safety thresholds were met when catches were near *MSY*; under rule 1 the catches were lower than *MSY* at the thresholds. These two rules illustrate that maximum yield is a function of the harvest strategy and that a constant rate strategy (rule 2) will in general outperform a constant yield strategy.

Indicator	Threshold	rule 1	rule 2
%<*Bmin*	5%	85.5	96.8
%<*Bmsy*	50%	97.5	101.0
%<20%*K*	5%	85.5	98.2
%collapse	5%	82.5	96.8

5.5 Evaluations

Based partly on results of the preliminary explorations, production runs were made with just over 1100 variants of rule 4. Harvest control rule parameters used to define these rules were:

Rule type	*par1*	4						
Close fishery threshold	*par2*	0.5						
Plateau left	*par3*	1.00	1.25	1.50	1.75	2.00		
Plateau width		0.4	0.8	1.2				
Step width	*par5*	0.25	0.50	0.75				
Plateau height	*par6*	40	45	50	55	60	70	80
Step increase	*par7*	0.15	0.20	0.25	0.30			
Min	*par8*	0.05						

The plateau width options shown were added to the plateau left parameter to obtain the plateau right parameter *par4*. The values of 45 and 55 t for *par6* were chosen after examining an initial set of runs using values from 40 to 80 t in increments of 10 t.

All combinations[5] of these parameters were run with the base case operating and with five robustness trials (see next section). Screening (described below) was done on the results of all the trials.

5.6 Robustness trials

Five robustness trials were run, involving a different model fit, two different recreational catch vectors, decreased model productivity and increased CPUE observation error.

The R1 trial used an alternative model fit. It was hoped that process error fitting could be used here, but that was too unstable (see Figure 24). This trial used a model fit based on a uniform prior on *r* with wide bounds (0.01 to 10.0). To obtain a positive definite Hessian matrix it was necessary to fix *p*, with 0.20 was chosen as the value (in previous work, results have not been sensitive to the choice of *p*). This trial was called NoPrior.

[5] but an error in the parameter generation procedure, discovered too late to be addressed, meant that not all 1260 combinations were run

The R2 and R3 trials used the high and low alternative recreational catch vectors described above in the data description (see Table 1 and Figure 3); these were called HiRec and LoRec respectively.
For these three alternative model fits, the model was fitted and run for 10 million McMC simulations as for the base case. Medians of the posteriors are compared in Table 11. Medians from the R1 trial were little different from the base case. The R2 trial had higher median *K* and *r* and higher sustainable yields, but the ratio of current biomass to indicators was smaller than in the base model. The R3 trial, with less recreational catch, showed the converse effects. R2 in some ways appeared to be a more productive model, and R3 a less productive model, than the base case model.

The R4 and R5 trials used the same estimation model as the base case but differed in projections. In R4 (LoProd), the projected productivity (a combination of the second and third terms of equation 24) was arbitrarily reduced by 75%. In R5 (HiObs), the standard deviation of CPUE observation error was increased by a factor of two when projecting CPUE observation deviations. This would decrease the autocorrelation of deviations, but no attempt was made to incorporate this effect.

All six models were used to run the same set of variants of rule 2 to determine the maximum total catch and the associated CPUE, the maximum commercial catch and associated CPUE, and total and commercial catches at the point where safety thresholds were reached. Maximum commercial catch always occurred at higher fishing intensity than total catch, because recreational catch decreased as abundance decreased. The relevant safety indicator (the first whose threshold was reached) was always the percentage of years with biomass less than *Bmin*: when this reached the 5% threshold the other safety indicators were always well below their thresholds. Results obtained from the six models are compared in Table 12. Trials R1 and R2 (NoPrior and HiRec) were more productive than the base case while trials R3 and R4 (LoRec and LoProd) were less productive. The R5 (HiObs) trial gave the same yield values as the base case, but with higher associated observed CPUE values.

5.7 Screening

From the approximately 1100 rules created using the parameter combinations described above, Table 13 compares the minimum and maximum values of indicators in the base case and robustness trials. The rules spanned a good range from conservative to aggressive: for instance, in the base case results the average commercial catch varied among rules from 37 to 80 t, while the mean CPUE varied from 1.1 to 2.2 kg/potlift. Some rules were very stable, with 7% AAVH, while others had 66% AAVH in the base case.

The TACCnow indicator ranged from 40 to 502 t.

R1 and R2 tended to show higher catch and CPUE indicators than the base case, but R1 had fewer rules that met the safety criteria. R3 was less different from the base case, and the directions of difference varied. R4 had lower catch and CPUE indicators than the base case, and had fewer rules that met the safety criteria. R5 showed far higher AAVH than the base case because of the increased observation error on CPUE.

Table 13 also shows the numbers of rules that met each safety threshold in each trial and that met all safety thresholds within a trial. Of the approximately 1100 rules, 619 rules met all safety thresholds in all trials. The first screening step accepted only these rules. This was a more brutal approach than usual with respect to robustness trials, but there is uncertainty about the productivity of CRA 9 that stems from the simple model, the new CPUE standardisation procedure and the uncertain recreational catch. In any case, the number of candidate rules that passed all safety criteria in all trials was high.

The RLFAWG rejected this step: some members thought that it might reject rules that failed in only one robustness trial, and would lead to a too-conservative pool of candidate rules. Accordingly, the RLFAWG was given a set of more than 1000 rules that passed the base case safety criteria. At the next meeting, the “final” rule candidates were chosen from the 112 rules described here.

After step 1 screening, the ranges of indicators from the 508 rules are compared in Table 14. Minimum catch and biomass indicators were higher in this set than they had been in the full set, many maximum indicators were lower, and of course the safety indicators were truncated at their upper thresholds. The maximum of TACCnow was truncated from 500 to 128 t.

The relation between average catch and CPUE is shown in Figure 30. This illustrates first the differences among trials: rules showed a higher CPUE for a given commercial catch in the robustness trials compared with the base case, except for trial R4 with lower productivity, showing much less CPUE for a given level of catch. Second, the figure shows limited variation in the relation within a trial.

The relation between AAVH and catch (Figure 31) showed much higher values in R5 than other trials because of the increased observation error, and also shows much more variability for a given catch level. This suggests the possibility for screening out rules on the basis of high AAVH.

Similarly, the relation between catch and minimum TACC (Figure 32) showed much variation within a trial. The base case and trial R2 tended to have higher minTACCs, and trials R4 and R5 tended to have lower values.

Step 2 of the screening rejected 131 rules that had TACCnow from 40 to less than 60 t. These rules seemed overly conservative: the current TACC has been 47 t for a long time; and current CPUE is the highest in recent times and exploitation rate is very low. Choosing a rule that sets a TACC lower than the present value would make no sense. Choosing a rule that set a TACC in the 50 to 60 t region would be little different from leaving the current TACC in place. In step 2, these 131 rules were removed, leaving 488.

Step 3 screening was based on the minTACC indicator, which differed widely (Figure 32): in the base case, the remaining rules varied between 10 and 45 t. Step 3 removed 308 rules with values less than 20 t, leaving 180 rules. The minTACC in R4 ranged from 11 to 32 t, with 40 less than 15 t. The second part of step 3 removed these, leaving a final set of 35 rule candidates.

The base case AAVH ranged from 9% to 24%. The final screening step removed 28 rules with AAVH higher than 18%, leaving a set of 112 rules. In this set, there was a tight relation between average commercial catch and average CPUE (Figure 33), although the range of average CPUE was narrower (from 1.88 to 2.11 kg/potlift) than the range of average commercial catch (42.4 to 55.8 t). The relation between average commercial and recreational catch was similar to that in Figure 33, with average recreational catch ranging only from 26 to 29 t.

The relation between average commercial catch and minimum TACC shows much scatter (Figure 34), providing a “choice frontier” (Bentley et al. 2003b). If minimum TACC is an important consideration over the other yield, abundance and stability indicators, then one could choose a rule from the upper right-hand edge: a rule with high minimum TACC for the chosen level of average commercial catch.

The relation between average commercial catch and %AAVH (Figure 35) also shows a choice frontier, this time at the lower edge, from which one could choose a rule with low average annual change for the given level of average catch.

The relation between minimum TACC and %AAVH (Figure 36) shows another choice frontier: rules 4041 and 4966 have high average minimum TACCs and high stability.

A simple viewer was constructed that allowed stakeholders to view and compare the rules in the set of 112 final candidates.

Choosing a set of final rules for NRLMG consideration involved two iterations of RLFAWG deliberations with stakeholder involvement. Commercial stakeholders would consider only rules with a TACCnow variable less than 70 t. Minimum TACC was a major consideration in choosing among

the alternatives. After discussion, the RLFAWG chose four rules to present to the NRLMG as "final" rule candidates (MPI unpublished):

> *The WG discussed the performance of the various decision rules that had been presented at the previous meeting … The WG agreed that large increases in the first year TACC were not desirable as they result in a very low minimum TACC over the projection period. Rules that mainly avoided the left hand slope were preferred. Because of concerns with the large changes seen in CPUE, some members felt that the plateau should be very wide to allow for the variability observed in the CPUE from year to year. A shallow stepped MP with low plateau height was shown to achieve the same result.*
>
> *The group supported a number of different rules which should be discussed with stakeholders. These were limited to first year increases up to 65 t only and had various plateau height options (40 to 50 t). Rules with parameter 2 (start of plateau CPUE value) at 1.0 appeared to avoid the slope area with high probability and this value appears to be a good choice for any chosen rule. Based on the production model the mean expected CPUE for most safe rules was between about 1.9 and 2.0 kg per potlift. More aggressive rules dropped this below 1.9 and higher safety rules resulted in mean CPUE above 2.0.*
>
> *From within the pool of rules that passed the safety criteria, the WG chose 4 rules to progress to discussion with stakeholders (rules 4041, 4942, 4103 and 4346).*

At the last minute, industry stakeholders added a rule they favoured. The five rules are shown in Figure 37 through Figure 41. The five sets of rule parameters are shown in Table 15 and major indicators in Table 16. Safety indicators are omitted because these rules all met the screening criteria in all trials. As well as differing in catch and abundance indicators in the base case, the various rules have different reactions to the robustness trials (Table 16). In most trials, CPUE shows more change than average commercial catch. The trial effects on catch and abundance indicators tend to be larger for the more aggressive rules – those with higher average commercial catch. The largest effects are in trial R4, with large decreases in catch and CPUE, and R5, with large decreases in minTACC and large increases in AAVH.

6. DISCUSSION

Although this study was not a stock assessment, the operating model was based on a simplified version of a stock assessment. An actual stock assessment should take length frequency and growth information into account as well as catch and CPUE, and would most likely use the length-based model of Haist et al. (2009).

The base case surplus production analysis, based on CPUE and estimated total catch, was a Bayesian procedure. The diagnostics were reasonably good for the base case observation error fit, but were very bad for the alternative process error fit. Although the base case involved analysis outside the model to construct a prior distribution for r, an alternative fit (robustness trial R1) without such a prior (but with fixed p) gave similar results.

The base case analysis suggested that the CRA 9 stock was overfished when the QMS was introduced in the early 1990s (Figure 22), then rebuilt steadily to a stock now well above *Bmsy*, and with current fishing intensity below that associated with *MSY*. Low current fishing intensity is consistent with the high proportions of large fish observed in logbook sampling (see Appendix A).

A major uncertainty in this analysis is recreational catch. The recent large-scale multi-species survey (NRB, unpublished data) initially suggested a 2011 catch of 26 t, which reduced to 18 t after the NRB error (see Appendix D) was corrected. However, the survey coverage in areas away from population centres was sparse – and extremely sparse on the west coast South Island. The mean weight used to scale from catch numbers to catch weight is also highly uncertain, with the value used by the recent recreational LSMS survey being substantially less than the value estimated from voluntary logbooks.

However, robustness trials R2 and R3 showed that large changes in assumed recreational catch had relatively small effects on rule indicators.

Another uncertainly involves standardised CPUE. This was the subject of considerable exploratory analysis in the past year, after previously estimated CPUE was found to be unreliable (Starr, unpublished data and in prep.). The numbers of vessels reporting is small, and the area potentially fishable is large, which may lead to local density being reflected in CPUE rather than overall abundance. High-grading has recently become important (see Appendix B), with nearly half the legal catch by weight returned to the sea in 2011. However, despite these problems, the RLFAWG was satisfied that the standardised CPUE used here was the best available information on relative abundance.

The analyses and operating models assume that CPUE is a linear index of abundance. The relation between stock size and CPUE is unknown for any stock, and the base case assessments for other lobster stocks assume a linear relation (e.g. Haist et al. 2013). This might be in error because of changes in fishing technology, especially better navigational and observational aids.

Another uncertainty involves the use of a simple surplus production model for the operating model instead of a more realistic and complex model. The simple model assumes that production and CPUE are both related to stock size. The more complex length-based model MSLM (Haist et al. 2009) explicitly considers lobster sex, size and maturity, considers the minimum legal size and models the different way the illegal and customary fisheries operate compared with the recreational and commercial fisheries; it considers the effects of season and uses finer-scale data and much more data than used here. Does a simple model do an adequate job for the purposes of an operating model? This question was explored using both types of model for CRA 5 (Breen 2011b), and it appeared that the simple model can do an adequate job. For CRA 5, harvest control rules likely to be accepted based on evaluation by the simple model would also be acceptable when evaluated by MSLM. Because problems with the simple model are likely to be situation-specific, some uncertainty still remains.

A final, minor, uncertainty involved the CPUE used to drive the rule. The evaluations used CPUE from a fishing year to determine TACC for the next fishing year. In reality, it is proposed that the rule will use the offset-year CPUE, which will contain six months of more recent data than the fishing year. The evaluations could not simulate this complication. However, the offset-year CPUE should perform better than the fishing year CPUE, being more up-to-date.

Because all the screened rules had passed arbitrary safety criteria, an important trade-off for industry to consider was that between mean commercial yield and CPUE. This is a difficult and complex decision that should ideally be determined by stakeholders. The relation between recreational catch and the commercial catch was negative, but the scale of change in recreational catch was much smaller than the scale of choice of average commercial catch.

Rule indicators tend to fall into the categories of safety, yield, abundance and stability (Bentley et al. 2003b). Safety is not an issue when considering the screened rules, where all the rules with low safety have been eliminated. Yield is reflected in average catch indicators, abundance in the biomass and CPUE indicators and stability by the average minimum TACC and the %AAVH. Relations among these are not simple, and the choice of a rule always depends strongly on how stakeholders see the abundance, stability and yield indicators in terms of priority.

The work suggests that management procedures are feasible for this stock and that a larger catch could safely be taken at this stage of stock abundance. The NRLMG went to consultation with rules 4041 and 4144, and the Minister accepted rule 4041 for the 2014–15 fishing year.

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Table 1: CRA 9 commercial catch, Section 111 catch, base case recreational catch (includes s. 111), two variants of recreational catch for robustness trials, illegal catch (actual MPI estimates in bold), customary catch, base case total catch and the two variants of total catch, 1963–2012. Commercial catch was interpolated (little grey cells) for 1974–78 and 1988–89.

Year	Comm. catch	S. 111 catch	Base Rec.	High Rec.	Low Rec.	Illegal catch	Cust.	Base total	hi rec total	lo rec total
1963	43.28	2.26	11.18	17.07	6.72	8.17	1.00	63.63	69.52	59.17
1964	72.06	2.26	11.51	17.63	6.89	13.60	1.00	98.18	104.29	93.55
1965	201.17	2.26	11.85	18.19	7.06	37.97	1.00	251.99	258.32	247.19
1966	174.42	2.26	12.19	18.74	7.23	32.92	1.00	220.52	227.08	215.56
1967	93.19	2.26	12.52	19.30	7.39	17.59	1.00	124.31	131.09	119.18
1968	95.24	2.26	12.86	19.86	7.56	17.98	1.00	127.08	134.08	121.78
1969	126.95	2.26	13.20	20.42	7.73	23.96	1.00	165.10	172.33	159.64
1970	44.86	2.26	13.53	20.98	7.90	8.47	1.00	67.86	75.31	62.23
1971	118.02	2.26	13.87	21.54	8.07	22.28	1.00	155.17	162.84	149.36
1972	87.93	2.26	14.21	22.10	8.23	16.60	1.00	119.73	127.62	113.75
1973	100.96	2.26	14.54	22.66	8.40	19.06	1.00	135.56	143.67	129.42
1974	100.87	2.26	14.88	23.21	8.57	12.91	1.00	129.67	138.00	123.36
1975	100.79	2.26	15.21	23.77	8.74	24.39	1.00	141.39	149.95	134.92
1976	100.70	2.26	15.55	24.33	8.91	19.56	1.00	136.81	145.59	130.16
1977	100.61	2.26	15.89	24.89	9.08	25.84	1.00	143.34	152.34	136.52
1978	142.92	2.26	16.22	25.45	9.24	36.67	1.00	196.81	206.04	189.83
1979	89.01	2.26	16.56	26.01	9.41	7.73	1.00	114.29	123.74	107.14
1980	97.15	2.26	16.20	25.41	9.23	11.08	1.00	125.43	134.64	118.46
1981	71.99	2.26	13.59	21.07	7.93	13.59	1.00	100.17	107.65	94.50
1982	59.13	2.26	11.44	17.50	6.85	11.16	1.00	82.73	88.79	78.14
1983	70.61	2.26	11.85	18.18	7.06	13.33	1.00	96.78	103.11	91.99
1984	80.77	2.26	11.07	16.88	6.66	15.24	1.00	108.08	113.90	103.68
1985	79.23	2.26	10.70	16.28	6.48	14.95	1.00	105.88	111.46	101.66
1986	93.25	2.26	11.88	18.23	7.07	17.60	1.00	123.73	130.08	118.92
1987	92.72	2.26	11.99	18.42	7.13	17.50	1.00	123.21	129.64	118.35
1988	76.91	2.26	11.30	17.28	6.78	4.91	1.00	94.13	100.10	89.61
1989	61.10	2.26	11.24	17.17	6.75	5.05	1.00	78.39	84.32	73.90
1990	45.29	2.26	11.17	17.06	6.72	**12.81**	1.00	70.28	76.17	65.82
1991	47.52	2.26	11.64	17.84	6.95	**21.91**	1.00	82.06	88.26	77.37
1992	45.67	2.26	12.85	19.85	7.56	31.00	1.00	90.52	97.52	85.22
1993	45.49	2.26	14.46	22.52	8.36	24.50	1.00	85.45	93.51	79.35
1994	45.24	2.26	13.77	21.38	8.02	**18.00**	1.00	78.01	85.62	72.26
1995	45.41	2.26	18.79	29.71	10.53	**12.00**	1.00	77.20	88.12	68.93
1996	46.94	2.26	14.44	22.49	8.35	12.00	1.00	74.38	82.43	68.29
1997	46.73	2.26	11.80	18.10	7.03	9.80	1.00	69.33	75.63	64.56
1998	46.89	2.26	20.68	32.86	11.47	7.60	1.00	76.17	88.35	66.96
1999	46.99	2.26	14.31	22.28	8.29	5.40	1.00	67.71	75.67	61.68
2000	47.00	2.26	19.71	31.24	10.99	3.20	1.00	70.91	82.44	62.18
2001	46.79	2.26	18.71	29.58	10.49	1.00	1.00	67.50	78.38	59.28
2002	47.00	2.26	20.65	32.80	11.46	1.00	1.00	69.64	81.79	60.45
2003	45.89	2.26	24.71	39.54	13.49	1.00	1.00	72.59	87.43	61.37
2004	46.98	2.26	31.43	50.70	16.85	1.00	1.00	80.40	99.68	65.82
2005	46.60	2.26	27.09	43.49	14.67	1.00	1.00	75.69	92.09	63.28
2006	47.00	2.26	24.39	39.02	13.33	1.00	1.00	73.39	88.02	62.33
2007	47.02	2.26	19.87	31.51	11.07	1.00	1.00	68.89	80.53	60.08
2008	46.97	2.26	15.10	23.58	8.68	1.00	1.00	64.07	72.55	57.65
2009	46.59	2.26	19.44	30.80	10.85	1.00	1.00	68.03	79.38	59.44
2010	46.99	2.26	37.42	60.65	19.84	1.00	1.00	86.41	109.64	68.83
2011	46.97	2.26	27.47	44.13	14.87	1.00	1.00	76.44	93.10	63.84
2012	47.00	2.26	45.83	74.63	24.05	1.00	1.00	94.84	123.63	73.05

Table 2: CRA 9 annual CPUE used in the operating model. The value for 1989 (grey cell) was missing and was interpolated from adjacent values.

Year	Arithmetic kg/day	Standardised kg/pot
1963	45.95	
1964	84.98	
1965	123.27	
1966	105.90	
1967	62.34	
1968	60.63	
1969	48.25	
1970	38.94	
1971	54.97	
1972	43.38	
1973	42.47	
1979		1.247
1980		1.356
1981		1.028
1982		0.859
1983		0.885
1984		0.844
1985		0.750
1986		0.869
1987		0.884
1988		0.880
1989		0.852
1990		0.824
1991		0.858
1992		0.930
1993		1.163
1994		0.935
1995		1.351
1996		1.137
1997		1.057
1998		1.404
1999		0.949
2000		1.187
2001		1.126
2002		1.473
2003		1.713
2004		2.114
2005		2.067
2006		2.132
2007		1.745
2008		1.299
2009		1.556
2010		2.270
2011		1.950
2012		2.983

Table 3: Estimation phases, lower and upper bounds and priors for each estimated parameter in the observation and process error surplus production models; prior type 0 is uniform and 2 is lognormal.

	Phase	Lower bound	Upper bound	Prior type	Prior mean	Prior CV
K	2	1	25	0	n.a.	n.a.
Binit	2	1	25	0	n.a.	n.a.
r	1	0.01	10	2	2.1	0.25
p	3	0.01	5	0	n.a.	n.a.
$\ln(q_{day})$	1	-20	-3	0	n.a.	n.a.
$\ln(q_{pot})$	1	-20	-3	0	n.a.	n.a.
σ_{day}	4	0.1	2	0	n.a.	n.a.
σ_{pot}	4	0.01	2	0	n.a.	n.a.

Table 4: A summary of the posterior distributions of *M* and growth parameters made from the CRA 9 tag-recapture data. The last line summarises the posterior distribution of estimated intrinsic rate of increase, made from a simple model. Columns are the minimum value, 5th quantile, median, 95th quantile and maximum.

	Min.	0.05	Median	0.95	Max.
M	0.03	0.06	0.11	0.20	0.39
galphaMale	5.19	7.32	8.98	10.92	13.52
gBetaMale	1.26	1.95	2.83	4.53	11.15
galphaFemale	1.61	7.23	11.72	17.31	25.56
gBetaFemale	0.61	0.78	1.02	1.52	2.05
GrowthCV	0.28	0.37	0.47	0.59	0.93
r	1.79	1.94	2.09	2.86	27 900

Table 5: CRA 9: Length-weight coefficients from Nokome Bentley (Trophia, unpublished data); weight (kg) is given by *a* times TW (mm) raised to the power of *b*.

	Male	Female
a	3.39E-06	1.04E-05
b	2.967	2.632

Table 6: CRA 9 surplus production model observation error fit: summaries of posterior distributions (5th and 95th quantiles, mean and median) of estimated and derived parameters from the McMC, and the MPD estimates; sdnr is the standard deviation of normalised residuals. Biomass and yields are shown in t.

	5%	Mean	Median	95%	MPD
function value	-50.14	-47.66	-47.24	-42.87	-51.61
negative log-likelihood for kg/day	-9.53	-8.06	-7.72	-4.98	-9.51
negative log-likelihood for kg/pot	-42.50	-40.87	-40.50	-37.40	-42.78
Binit	1 139.5	2 055.0	4 023.0	14 405.0	2 123.1
K	1 130.0	1 320.0	1 377.7	1 830.0	1 287.5
r	1.352	1.894	1.921	2.572	1.937
p	0.08	0.11	0.12	0.17	0.12
ln(*q*) for kg/day	-9.940	-9.707	-9.703	-9.452	-9.692
ln(*q*) for kg/pot	-13.17	-12.90	-12.91	-12.70	-12.84
sigma for kg/day	0.113	0.223	0.245	0.451	0.168
sigma for kg/pot	0.147	0.185	0.187	0.236	0.172
sdnr for kg/day	0.651	1.603	2.258	6.094	2.146
sdnr for kg/pot	0.781	0.990	0.995	1.234	1.040
B2012	706.4	805.7	831.8	1 040.0	780.4
B2012/K	0.540	0.611	0.608	0.662	0.606
Bmin	260	334	344	460	307
Bmsy	441	513	535	704	500
B2012/Bmsy	1.399	1.571	1.564	1.701	1.561
MSY	97.6	101.8	102.2	107.8	100.9
CSP	79.7	85.0	86.1	96.2	85.5

Table 7: CRA 9 surplus production model observation error fit: correlations among the estimated and derived parameters in the McMC. Grey indicates cells with more than 0.70 absolute correlation.

	Binit	***K***	***r***	***p***	**ln(*q*) days**	**ln(*q*) pots**	**sdnr days**	**sdnr pots**	***B12***	***B12/B0***	***Bmin***	***Bmsy***	***B12/Bmsy***	***MSY***	***CSP***
Binit	1.00														
K	-0.41	1.00													
r	0.07	-0.22	1.00												
p	0.17	-0.41	-0.76	1.00											
ln(*q*) for kg/day	-0.34	0.34	-0.09	-0.06	1.00										
ln(q) for kg/pot	0.25	-0.69	0.16	0.29	0.00	1.00									
sdnr kg/day	0.75	-0.60	0.10	0.28	-0.43	0.40	1.00								
sdnr kg/pot	0.05	-0.03	-0.02	0.02	-0.02	-0.05	0.02	1.00							
B2012	-0.40	0.92	-0.22	-0.33	0.34	-0.85	-0.57	-0.01	1.00						
B2012/K	0.23	-0.63	0.08	0.36	-0.15	0.03	0.38	0.04	-0.27	1.00					
Bmin	-0.22	0.70	-0.16	-0.30	-0.10	-0.95	-0.36	0.02	0.82	-0.10	1.00				
Bmsy	-0.41	1.00	-0.28	-0.35	0.34	-0.69	-0.60	-0.03	0.92	-0.62	0.70	1.00			
B2012/Bmsy	0.21	-0.58	0.24	0.19	-0.15	-0.02	0.34	0.03	-0.22	0.98	-0.04	-0.58	1.00		
MSY	-0.33	0.50	-0.13	-0.08	0.67	-0.32	-0.38	-0.03	0.64	0.07	0.21	0.51	0.09	1.00	
CSP	-0.36	0.80	-0.21	-0.29	0.46	-0.16	-0.52	-0.04	0.54	-0.87	0.16	0.80	-0.87	0.40	1.00

Table 8: CRA 9 surplus production model process error fit: summaries of posterior distributions (5th and 95th quantiles, mean and median) of estimated and derived parameters from the McMC, and the MPD estimates; sdnr is the standard deviation of normalised residuals. Biomass and yields are shown in t.

	5%	Mean	Median	95%	MPD
function value	-47.22	-44.58	-44.17	-39.73	-48.02
likelihood for kg/day	-10.92	-8.66	-8.34	-4.13	-10.63
likelihood for kg/pot	-38.36	-37.15	-37.00	-35.11	-38.08
K	685	1 760	157 808	474 000	811
r	1.295	1.932	1.997	2.943	1.978
p	0.02	0.13	0.15	0.34	0.24
ln(*q*) for kg/day	-13.369	-8.577	-9.072	-8.06	-10.63
ln(*q*) for kg/pot	-18.73	-13.46	-14.24	-12.43	-38.08
sigma for kg/day	0.198	0.198	0.198	0.198	0.198
sigma for kg/pot	0.192	0.192	0.192	0.192	0.192
sdnr for kg/day	0.934	1.154	1.170	1.533	1.059
sdnr for kg/pot	0.991	1.021	1.021	1.060	1.032
B2012	745	2 090	57 741	407 200	1038
B2012/K	0.269	1.247	1.238	2.079	1.279
Bmin	187	526	14 517	102 050	261
Bmsy	282	688	58 709	179 000	331
B2012/Bmsy	0.721	3.130	3.146	5.408	3.135
MSY	108.5	162.6	2 325.1	11 810.0	126.7
CSP	-8 465.0	-137.9	-1 578.5	1 640.0	-125.0

Table 9: Rule 1 explorations: medians of indicators for various constant catches (*par2*, t) from exploratory runs with the operating model; %coll: the percentage of runs in which biomass fell to 1 t or less. Catches and biomass are in t; CPUE in kg/pot.

par2	Min. Bio.	Mean Bio.	Min. TACC	Min. Comm.	Mean Comm.	Min. Rec.	Mean Rec.	Mean Tot.	Min. CPUE	Mean CPUE	% AAVH	% <*Bmin*	% <*Bmsy*	% <20%*K*	% %coll
0	691	1 067	0	0.0	0.0	23.7	36.7	40.9	1.474	2.665	0	0.03	0.28	0.01	0.00
5	671	1 038	5	5.0	5.0	23.2	35.8	45.0	1.432	2.593	0	0.07	0.41	0.03	0.08
10	660	1 015	10	10.0	10.0	22.5	34.9	49.2	1.394	2.540	0	0.05	0.56	0.01	0.04
15	638	992	15	15.0	15.0	22.0	34.2	53.5	1.360	2.472	0	0.11	0.73	0.04	0.04
20	619	971	20	20.0	20.0	21.2	33.2	57.5	1.315	2.412	0	0.13	0.96	0.05	0.00
25	601	946	25	25.0	25.0	20.6	32.5	61.7	1.270	2.360	0	0.23	1.40	0.10	0.16
30	576	920	30	30.0	30.0	19.6	31.5	65.7	1.217	2.289	0	0.34	2.10	0.14	0.24
35	549	884	35	35.0	35.0	18.8	30.4	69.7	1.172	2.214	0	0.83	3.34	0.50	0.92
40	521	864	39	39.0	39.0	18.0	29.8	73.1	1.114	2.161	0	0.93	4.30	0.46	0.92
45	500	843	43	43.0	43.0	17.1	28.9	76.2	1.057	2.096	0	1.49	5.64	0.88	2.16
47.5	473	819	47	47.0	47.0	16.3	28.1	79.4	1.026	2.046	0	2.19	7.69	1.43	3.04
50	441	785	51	51.0	51.0	15.1	27.2	82.5	0.961	1.976	0	3.06	10.0	2.02	4.52
52.5	409	762	55	55.0	55.0	14.0	26.2	85.5	0.886	1.903	0	4.90	13.9	3.26	7.96
55	374	729	59	59.0	59.0	12.9	25.2	88.4	0.817	1.823	0	7.56	18.5	5.42	12.3
57.5	339	701	63	63.0	63.0	11.6	24.2	91.5	0.747	1.759	0	9.8	22.4	7.2	15.8
60	285	654	67	67.0	67.0	9.8	22.6	93.8	0.641	1.643	0	13.4	28.4	10.4	23.5
62.5	217	617	71	71.0	71.0	7.4	21.4	96.4	0.485	1.540	0	17.9	34.3	14.0	32.5
65	150	574	75	75.0	75.0	5.0	19.8	98.5	0.339	1.430	0	23.0	40.7	18.5	41.2
67.5	11	522	79	7.6	76.8	0.0	17.8	98.2	0.025	1.301	0	28.4	46.9	23.2	49.9
70	1	470	83	0.7	77.3	0.0	16.0	97.5	0.002	1.156	0	33.9	52.3	28.4	60.2
75	1	421	87	0.7	77.1	0.0	14.2	95.0	0.002	1.042	0	39.5	57.8	33.4	68.4
80	1	375	91	0.7	77.3	0.0	12.6	93.2	0.002	0.916	0	45.4	63.7	38.9	75.2
85	1	323	97	0.7	76.0	0.0	11.0	90.2	0.002	0.808	0	52.7	69.2	46.3	84.3
90	1	292	103	0.7	76.6	0.0	9.7	89.6	0.002	0.719	0	59.0	74.5	52.4	92.3
95	1	255	109	0.7	75.1	0.0	8.4	86.3	0.002	0.639	0	65.6	79.5	59.0	96.4
100	1	234	115	0.7	74.9	0.0	7.6	85.5	0.002	0.577	0	69.6	82.1	63.3	97.9
110	1	214	121	0.7	74.9	0.0	6.9	84.6	0.002	0.534	0	73.2	84.4	66.9	99.0
120	1	200	127	0.7	74.2	0.0	6.4	83.4	0.002	0.498	0	76.5	86.3	70.4	99.4
130	1	189	133	0.7	75.1	0.0	5.9	83.5	0.002	0.470	0	79.0	88.1	73.1	99.8
140	1	178	139	0.7	73.9	0.0	5.5	81.8	0.002	0.441	0	81.0	89.2	75.3	99.7
150	1	172	145	0.7	74.4	0.0	5.3	82.0	0.002	0.427	0	82.3	90.1	76.8	100.0

Table 10: Rule 2 explorations: medians of indicators for various multipliers (*par2*) from exploratory runs with the operating model; see caption for Table 9.

par2	Min. Bio.	Mean Bio.	Min. TACC	Min. Comm.	Mean Comm.	Min. Rec.	Mean Rec.	Mean Tot.	Min. CPUE	Mean CPUE	% AAVH	% <*Bmin*	% <*Bmsy*	% <20%*K*	% %coll
0	692.0	1 062.4	0	0	0.0	23.7	36.6	40.9	1.469	2.658	0.0	0.0	0.3	0.0	0.0
5	654.2	1 006.8	8	8	12.7	22.5	34.5	51.5	1.384	2.508	11.1	0.1	0.6	0.0	0.0
10	615.2	950.1	15	15	24.0	21.0	32.7	61.0	1.302	2.371	11.8	0.1	0.8	0.0	0.0
15	565.0	893.2	21	21	33.9	19.5	30.9	69.0	1.205	2.242	12.5	0.2	1.8	0.1	0.1
20	519.1	849.8	26	26	42.9	18.0	29.2	76.3	1.125	2.118	13.3	0.4	3.0	0.1	0.1
25	478.1	802.1	30	30	50.8	16.4	27.6	82.7	1.017	2.004	14.0	0.7	5.4	0.3	0.5
30	424.2	751.6	32	32	56.8	14.6	25.9	87.1	0.923	1.876	15.1	1.3	9.5	0.6	0.7
35	379.8	710.5	34	34	62.6	13.0	24.4	91.2	0.834	1.762	16.2	2.2	14.2	1.1	1.1
40	347.1	677.9	34	34	66.7	12.0	23.3	94.2	0.772	1.688	16.9	3.4	19.0	1.8	2.3
45	318.9	648.0	34	34	70.2	10.8	22.3	96.8	0.701	1.616	17.7	4.9	24.1	2.7	3.9
47.5	273.6	613.4	33	33	72.9	9.4	21.1	98.2	0.614	1.527	19.1	7.2	30.8	4.2	5.5
50	249.1	586.2	32	32	75.7	8.6	20.2	100.2	0.564	1.460	19.9	9.2	35.8	5.4	7.6
52.5	209.5	552.0	29	29	76.9	7.1	19.0	100.2	0.483	1.381	21.5	12.8	42.4	8.1	12.2
55	184.3	529.8	27	27	78.6	6.3	18.1	101.0	0.421	1.315	22.8	15.7	47.6	10.0	15.7
57.5	146.7	499.8	23	23	79.4	5.0	17.1	100.8	0.339	1.239	24.8	19.9	53.8	13.1	21.4
60	122.5	479.1	21	21	80.8	4.2	16.4	101.4	0.287	1.191	26.3	23.4	58.5	15.8	24.7
62.5	89.6	449.8	16	16	80.5	3.1	15.4	100.1	0.212	1.117	28.8	27.7	63.3	19.1	31.0
65	57.7	426.8	11	11	80.2	2.0	14.6	99.0	0.138	1.055	31.3	32.5	68.0	22.9	39.5
67.5	38.4	406.1	8	8	80.6	1.3	13.9	98.7	0.094	1.012	34.1	36.2	71.2	25.6	43.0
70	6.0	385.4	1	1	80.4	0.2	13.2	97.9	0.014	0.956	36.6	40.2	74.5	29.2	50.0
75	1.0	366.5	0	0	79.7	0.0	12.4	96.3	0.003	0.902	40.0	44.5	77.4	32.9	56.2
80	1.0	345.9	0	0	79.5	0.0	11.9	95.6	0.003	0.865	42.3	47.8	79.9	35.8	62.8
85	1.0	318.7	0	0	78.0	0.0	10.9	93.2	0.002	0.793	47.5	54.2	83.6	41.8	71.2
90	1.0	298.5	0	0	76.9	0.0	10.2	91.2	0.002	0.745	52.0	59.1	85.9	46.3	77.4
95	1.0	280.1	0	0	76.1	0.0	9.5	89.6	0.002	0.692	55.7	63.4	88.1	50.3	83.1
100	1.0	261.7	0	0	75.1	0.0	8.9	87.9	0.002	0.646	59.7	67.8	89.9	55.0	87.2
110	1.0	243.6	0	0	73.9	0.0	8.3	86.2	0.002	0.606	63.3	70.9	91.0	58.2	90.2
120	1.0	232.0	0	0	73.9	0.0	7.9	85.6	0.002	0.573	66.7	73.9	92.1	61.5	93.8
130	1.0	217.6	0	0	73.0	0.0	7.5	84.4	0.002	0.547	69.9	76.6	93.0	64.5	94.7
140	1.0	209.0	0	0	72.5	0.0	7.1	83.5	0.002	0.518	73.7	78.7	93.7	67.0	96.4
150	1.0	200.3	0	0	72.8	0.0	6.9	83.4	0.002	0.499	75.2	80.6	94.3	69.3	97.7

Table 11: Comparison of medians of posteriors from the base case model and the R1–R3 robustness trials; catches and biomass are in t.

	Base	NoPrior R1	HiRec R2	LoRec R3
function value	-47.66	-48.55	-47.82	-47.69
negative log-likelihood for kg/day	-8.06	-7.92	-7.75	-8.05
negative log-likelihood for kg/pot	-40.87	-40.97	-41.31	-40.95
Binit	2 055	1 830	1 120	2 036
K	1 320	1 360	1 780	1 328
r	1.894	1.121	1.926	1.871
p	0.11	0.20	0.10	0.11
ln(*q*) for kg/day	-9.71	-9.68	-9.54	-9.74
ln(*q*) for kg/pot	-12.9	-12.9	-13.0	-13.0
sigma for kg/day	0.223	0.243	0.307	0.228
sigma for kg/pot	0.185	0.184	0.183	0.184
sdnr for kg/day	1.603	1.396	0.921	1.498
sdnr for kg/pot	0.990	0.993	0.986	0.991
B2012	805.7	843.0	918.0	859.9
B2012/K	0.611	0.618	0.520	0.647
Bmin	334	352	373	355
Bmsy	513	546	686	515
Bcurr/Bmsy	1.571	1.539	1.349	1.669
MSY	101.8	103.0	115.9	95.6
CSP	85.0	86.1	108.0	74.6
Umsy	0.197	0.187	0.169	0.184

Table 12: Comparing median catch indicators, and their associated median CPUE, from a set of rule 2 variants run under the base case and robustness trials; catches and biomass are in t; CPUE in kg/pot.. MSCommY is maximum commercial catch. The lower four rows are based on the *Bmin* indicator reaching its 5% threshold.

	Base	NoPrior R1	HiRec R2	LoRec R3	LoProd R4	HiObs R5
MSY	101.4	105.9	115.7	95.1	78.5	101.4
meanCPUE	1.26	1.30	1.44	1.28	1.20	1.33
MSCommY	81.4	85.3	83.2	82.3	59.5	81.4
mean CPUE at <*Bmsy* = 5%	1.15	1.11	1.17	1.16	1.07	1.21
meanTotal	95.6	100.1	112.2	87.1	75.6	95.6
meanComm	69.1	72.5	71.8	70	50.3	69.1
CPUE	1.61	1.66	1.67	1.63	1.52	1.68

Table 13: From the approximately 1100 production rules evaluated from the rule 3 family, the minimum and maximum values of indicators in the base case and five robustness trials. The lower part of the table shows the numbers of rules that were above each safety indicator threshold, and the number that met all four thresholds.

			NoPrior		HiRec		LoRec		LoProd		HiObs	
	Base	Base	R1	R1	R2	R2	R3	R3	R4	R4	R5	R5
Indicator	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
minBio	65.6	545.5	70.4	597.0	70.0	646.0	64.9	588.2	67.5	508.7	1.0	550.4
meanBio	442.7	885.8	481.5	934.3	487.1	1033.4	472.6	944.4	359.6	774.5	403.5	888.9
minTACC	0.0	45.0	0.0	50.0	0.0	51.9	0.0	46.1	0.0	33.0	0.0	23.2
minComm	0.0	45.0	0.0	50.0	0.0	51.9	0.0	46.1	0.0	33.0	0.0	23.2
meanComm	36.8	79.4	37.4	83.1	38.2	81.1	37.2	80.6	33.6	59.0	36.1	78.1
minRec	2.0	18.7	2.1	19.8	3.1	31.9	1.1	10.9	2.3	17.4	0.0	18.8
meanRec	15.2	30.4	15.8	31.2	24.1	50.8	8.7	17.6	12.4	26.5	13.6	30.4
meanTotal	71.1	100.1	72.9	104.7	92.8	114.4	58.9	94.0	64.1	78.6	70.8	99.3
minCPUE	0.159	1.163	0.164	1.228	0.156	1.259	0.144	1.182	0.163	1.054	0.003	0.856
meanCPUE	1.108	2.199	1.137	2.236	1.116	2.345	1.112	2.243	0.898	1.921	1.057	2.315
AAVH	7.0	65.9	6.0	54.7	7.4	64.1	7.2	65.6	5.4	62.4	14.6	94.0
%<*Bmin*	0.2	28.6	0.5	27.5	0.2	29.7	0.2	29.3	0.3	43.7	0.2	38.1
%<*Bmsy*	2.3	64.4	2.8	63.1	5.5	79.9	1.7	59.8	4.8	83.0	2.2	69.5
%<20%*K*	0.1	19.7	0.2	19.4	0.1	29.5	0.1	18.9	0.1	29.3	0.1	28.4
%collapse	0.0	34.2	0.6	37.3	0.0	36.4	0.0	37.1	0.0	31.0	0.0	58.0
	Rules meeting thresholds for											
Bmin	1019		998		1032		1013		758		788	
Bmsy	1250		1252		1165		1256		1050		1235	
20%K	1145		1143		1037		1163		979		966	
collapse	1089		998		1087		1057		1050		794	
all	1019		994		1031		1013		758		763	

Table 14: From the 619 production rules that met all safety criteria in all trials, the minimum and maximum values of indicators in the base case and five robustness trials.

			NoPrior		HiRec		LoRec		LoProd		HiObs	
	Base	Base	R1	R1	R2	R2	R3	R3	R4	R4	R5	R5
Indicator	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
minBio	348.5	545.5	392.9	597.0	400.8	646.0	364.7	588.2	306.1	508.7	303.9	550.4
meanBio	693.1	885.8	745.5	934.3	787.5	1033.4	737.6	944.4	584.3	774.5	679.5	888.9
minTACC	10.2	45.0	12.0	45.0	11.8	45.0	10.3	45.0	7.2	33.0	1.6	23.2
minComm	10.2	45.0	12.0	45.0	11.8	45.0	10.3	45.0	7.2	33.0	1.6	23.2
meanComm	36.8	64.4	37.4	66.6	38.2	67.6	37.2	65.4	33.6	51.8	36.1	65.4
minRec	11.9	18.7	12.9	19.8	19.9	31.9	6.8	10.9	10.5	17.4	10.2	18.8
meanRec	23.7	30.4	24.7	31.2	38.8	50.8	13.7	17.6	20.0	26.5	23.2	30.4
meanTotal	71.1	92.4	72.9	95.9	92.8	110.8	58.9	83.4	64.1	76.5	70.8	93.1
minCPUE	0.758	1.163	0.818	1.228	0.807	1.259	0.773	1.182	0.671	1.054	0.534	0.856
meanCPUE	1.718	2.199	1.763	2.236	1.794	2.345	1.744	2.243	1.451	1.921	1.772	2.315
AAVH	7.0	39.7	6.0	30.9	7.4	36.9	7.2	39.0	5.4	44.3	14.6	67.1
%<*Bmin*	0.2	2.8	0.5	3.3	0.2	2.6	0.2	2.9	0.3	5.0	0.2	4.9
%<*Bmsy*	2.3	17.0	2.8	16.5	5.5	31.7	1.7	13.5	4.8	33.5	2.2	21.0
%<20%*K*	0.1	1.4	0.2	1.7	0.1	2.6	0.1	1.3	0.1	2.5	0.1	2.9
%collapse	0.0	1.7	0.6	2.8	0.0	2.0	0.0	2.2	0.0	1.9	0.0	5.0

Table 15: CRA 9: parameters for the five rules presented to the NRLMG; also shown are the TACCs (t) that would result from the 2013 offset-year CPUE of 3.1409 kg/potlift.

Serial Number	Intercept par 2	Plateau left par 3	Plateau right par 4	Step width par 5	Plateau height par 6	Step height par 7	Min change par 8	2014–15 TACC
4041	0.5	1.00	1.40	0.75	40	0.15	0.05	60.84
4103	0.5	1.00	1.80	0.75	40	0.25	0.05	62.50
4346	0.5	1.25	2.45	0.75	50	0.20	0.05	60.00
4942	0.5	1.00	1.80	0.75	45	0.20	0.05	64.80
4144	0.5	1.00	2.20	0.50	40	0.30	0.05	67.60

Table 16: Major indicators from the five rules presented to the NRLMG.

4041	**Base**	**R1**	**R2**	**R3**	**R4**	**R5**
TACCnow	60.8					
minBio	471.3	520.2	564.9	507.0	386.8	465.9
meanBio	812.5	864.2	948.4	868.1	671.9	808.8
minTACC	40.0	40.0	40.0	40.0	26.4	19.7
minComm	40.0	40.0	40.0	40.0	26.4	19.7
meanComm	48.4	48.8	49.6	48.8	44.9	49.0
minRec	16.1	17.4	28.0	9.5	13.3	15.9
meanRec	27.9	29.0	46.8	16.2	23.1	27.7
meanTotal	80.4	82.0	100.7	69.3	72.1	81.0
minCPUE	1.01	1.08	1.11	1.04	0.83	0.74
meanCPUE	2.02	2.07	2.16	2.07	1.67	2.11
AAVH	8.8	7.1	8.8	9.1	8.9	18.4
4103	**Base**	**R1**	**R2**	**R3**	**R4**	**R5**
TACCnow	62.5					
minBio	472.6	523.2	557.2	505.8	402.4	455.8
meanBio	807.9	863.0	951.0	869.7	675.4	793.2
minTACC	40.0	40.0	40.0	40.0	28.5	19.2
minComm	40.0	40.0	40.0	40.0	28.5	19.2
meanComm	48.5	49.2	50.5	49.1	43.9	50.6
minRec	16.2	17.4	27.7	9.4	13.8	15.7
meanRec	27.8	28.9	46.4	16.2	23.3	27.4
meanTotal	80.6	82.3	101.1	69.6	71.6	82.2
minCPUE	1.02	1.08	1.11	1.04	0.85	0.74
meanCPUE	2.02	2.06	2.15	2.06	1.69	2.08
AAVH	13.1	10.8	13.2	13.4	11.3	24.6
4346	**Base**	**R1**	**R2**	**R3**	**R4**	**R5**
TACCnow	60.0					
minBio	450.8	497.4	543.0	483.7	361.2	447.8
meanBio	796.0	845.2	930.9	848.2	646.1	786.7
minTACC	31.5	36.3	38.3	33.3	18.1	14.8
minComm	31.5	36.3	38.3	33.3	18.1	14.8
meanComm	51.4	51.7	52.7	51.7	47.5	52.3
minRec	15.5	16.6	27.0	9.0	12.3	15.4
meanRec	27.3	28.3	45.7	15.8	22.1	27.1
meanTotal	83.0	84.3	102.6	71.8	73.9	83.8
minCPUE	0.97	1.04	1.07	1.00	0.77	0.72
meanCPUE	1.98	2.03	2.12	2.02	1.61	2.06
AAVH	8.8	7.6	8.9	9.0	11.6	21.7

4346	**Base**	**R1**	**R2**	**R3**	**R4**	**R5**
TACCnow	64.8					
minBio	444.5	495.9	527.3	481.0	354.4	432.4
meanBio	788.1	842.2	920.1	845.5	643.7	778.9
minTACC	42.0	45.0	45.0	45.0	23.8	18.2
minComm	42.0	45.0	45.0	45.0	23.8	18.2
meanComm	51.8	52.5	53.4	52.4	47.2	53.0
minRec	15.3	16.6	26.4	8.8	12.1	14.9
meanRec	27.1	28.1	45.0	15.7	22.0	26.7
meanTotal	83.2	84.9	102.7	72.3	73.5	84.2
minCPUE	0.96	1.03	1.05	0.98	0.76	0.70
meanCPUE	1.96	2.01	2.09	2.00	1.60	2.03
AAVH	10.9	8.9	11.1	11.1	10.4	21.6
4346	**Base**	**R1**	**R2**	**R3**	**R4**	**R5**
TACCnow	67.6					
minBio	482.1	533.5	571.6	510.7	410.0	422.8
meanBio	818.5	870.8	947.0	870.1	690.7	777.6
minTACC	40.0	40.0	40.0	40.0	29.8	15.2
minComm	40.0	40.0	40.0	40.0	29.8	15.2
meanComm	46.8	47.5	49.1	47.5	42.0	51.7
minRec	16.4	17.8	28.4	9.6	14.2	14.6
meanRec	28.1	29.2	46.7	16.3	23.8	26.8
meanTotal	79.2	81.0	100.1	68.1	70.2	82.9
minCPUE	1.03	1.11	1.12	1.06	0.87	0.69
meanCPUE	2.04	2.09	2.16	2.08	1.73	2.03
AAVH	15.6	13.6	17.2	16.3	10.1	30.0

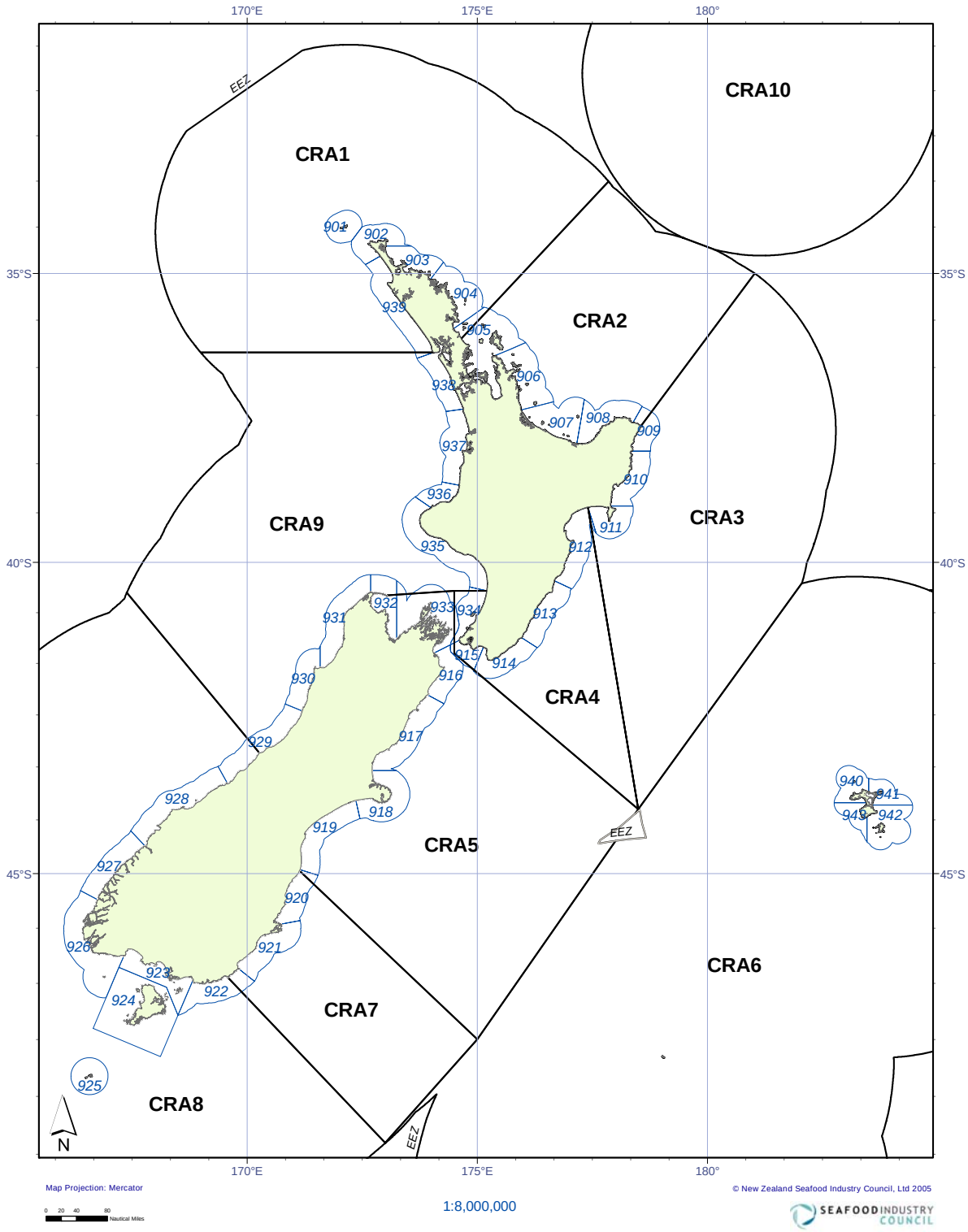

Figure 1: Map of rock lobster statistical areas and Quota Management Areas.

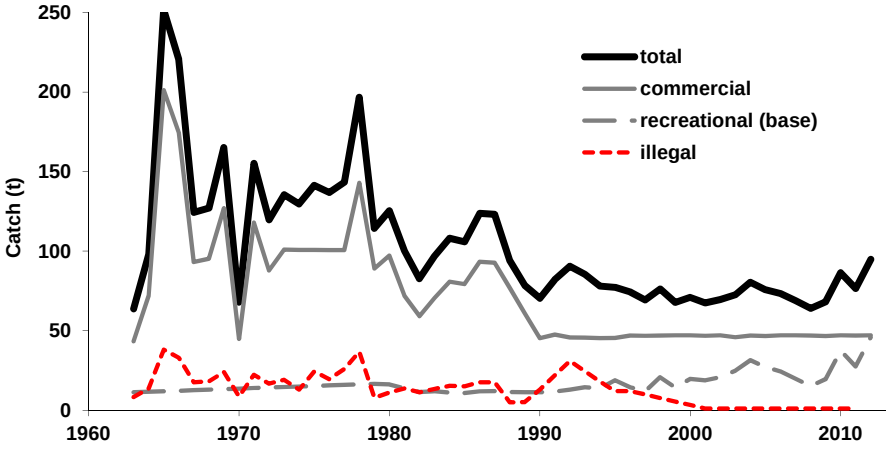

Figure 2: Total, commercial, estimated recreational and illegal catch vectors from CRA 9, 1963–2012 (see Table 1).

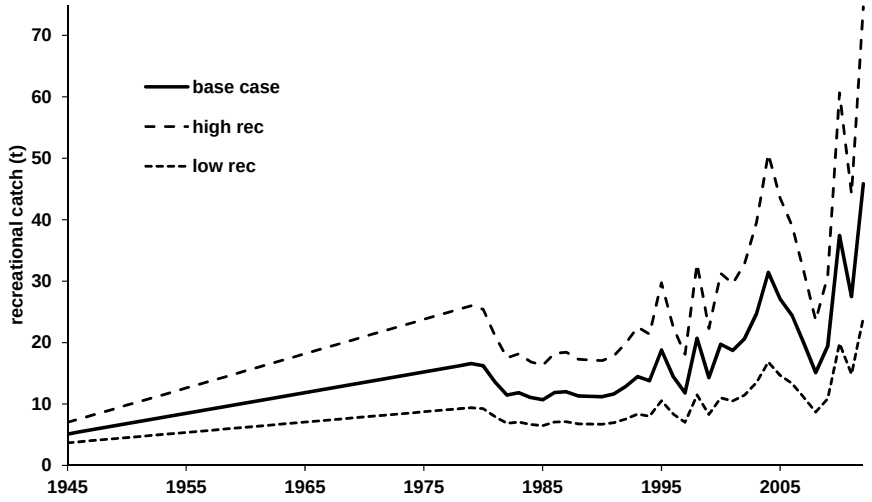

Figure 3: Comparing the base case and two alternative recreational catch vectors; all include the s. 111 catch.

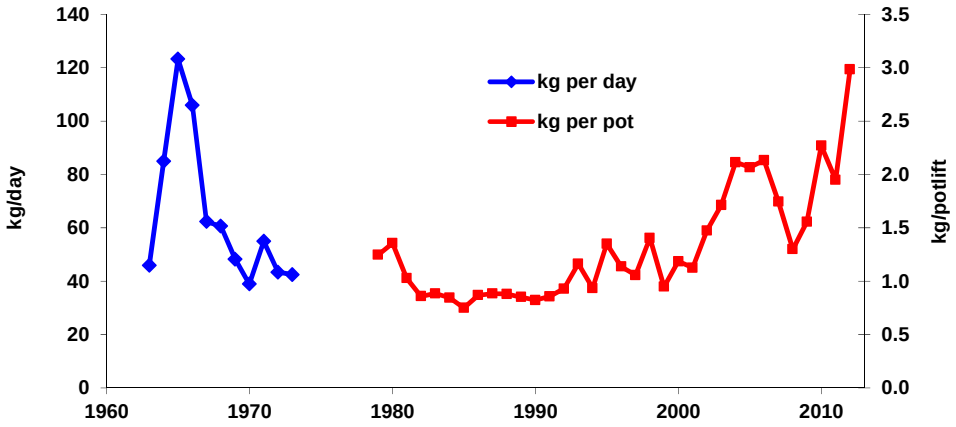

Figure 4: Annual arithmetic catch per day (blue diamonds) and standardised catch per potlift from CRA 9.

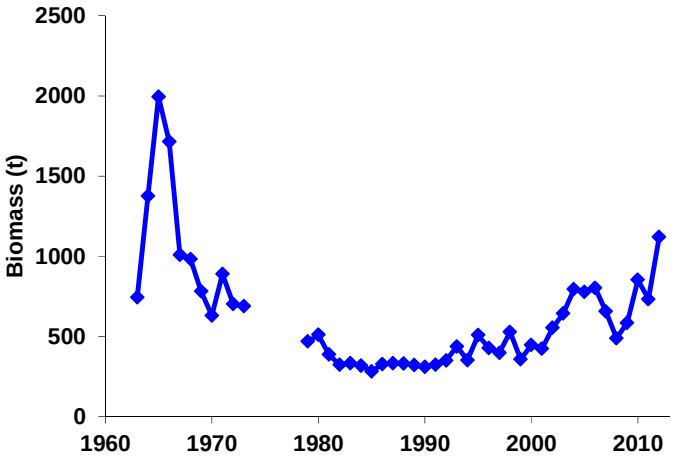

Figure 5: CRA 9 biomass estimated from CPUE using the simple method described in the text.

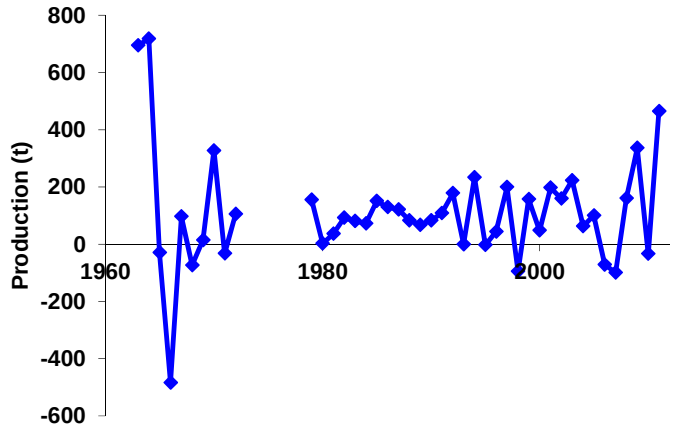

Figure 6: Annual CRA 9 production estimated from catch and CPUE using the simple method described in the text.

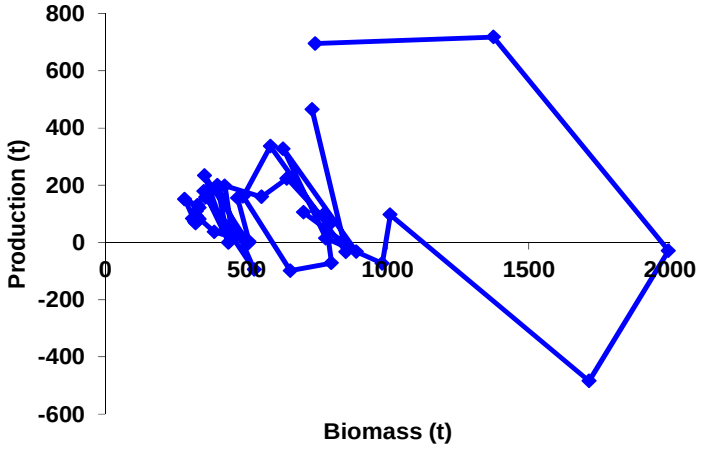

Figure 7: Annual CRA 9 production estimates plotted against estimated biomass, 1963–2012. The 1963 point is at the top left; 2011 is in the top centre where the line stops.

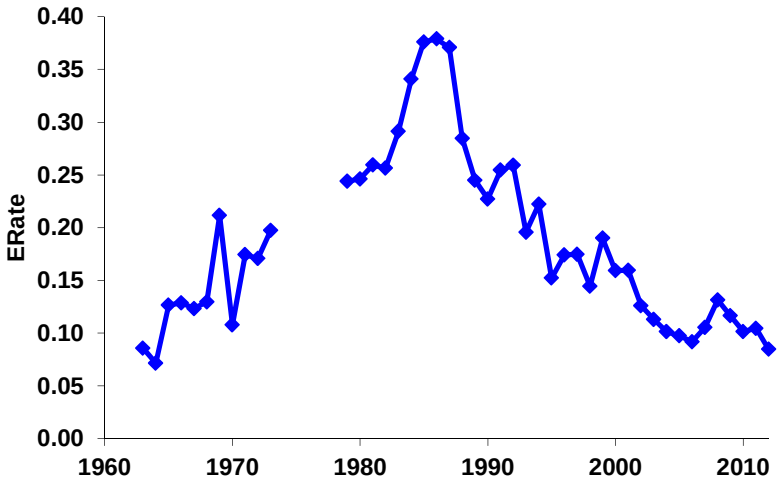

Figure 8: CRA 9 exploitation rate estimated from catch and CPUE using the simple method described in the text.

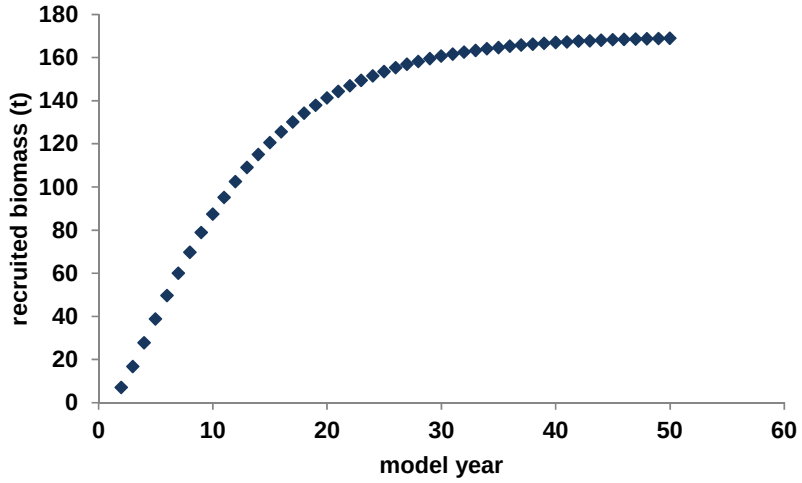

Figure 9: A biomass trajectory from the simple growth and mortality model used to estimate *r* from tag-recapture and mortality prior information.

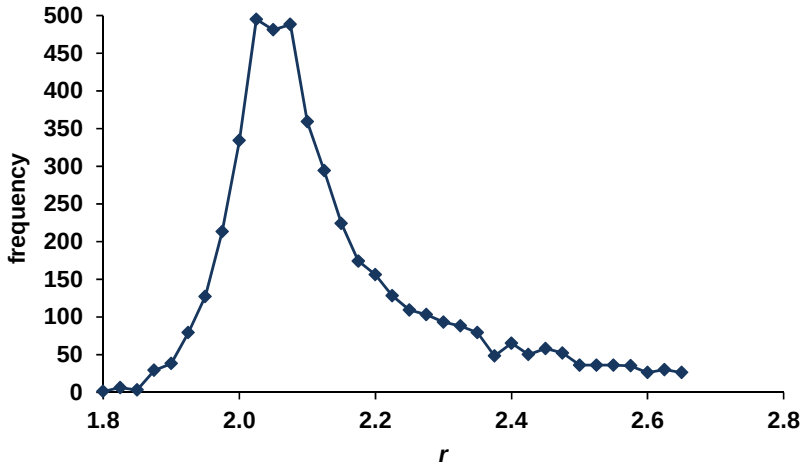

Figure 10: Posterior distribution of *r* from the simple growth and mortality model.

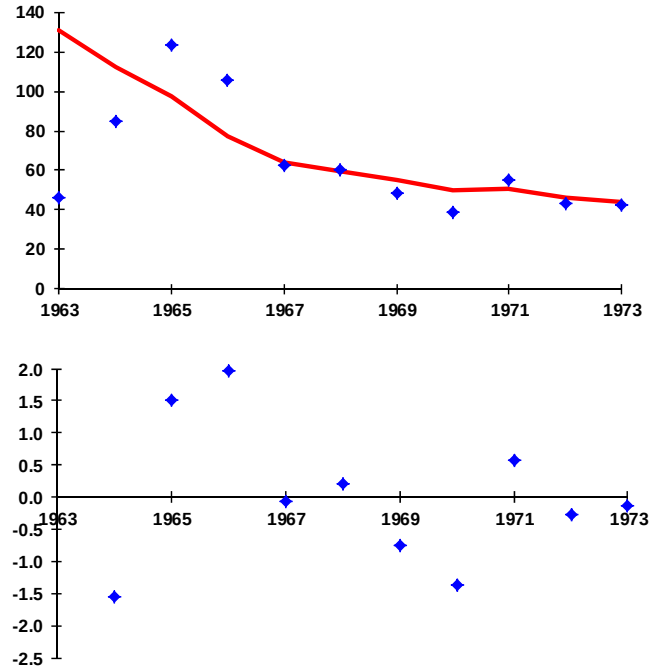

Figure 11: Surplus production model observation error fit: CPUE in kg/day (upper) from the base case MPD: diamonds are the observed and the line is the predicted CPUE; and residuals from the fit (lower).

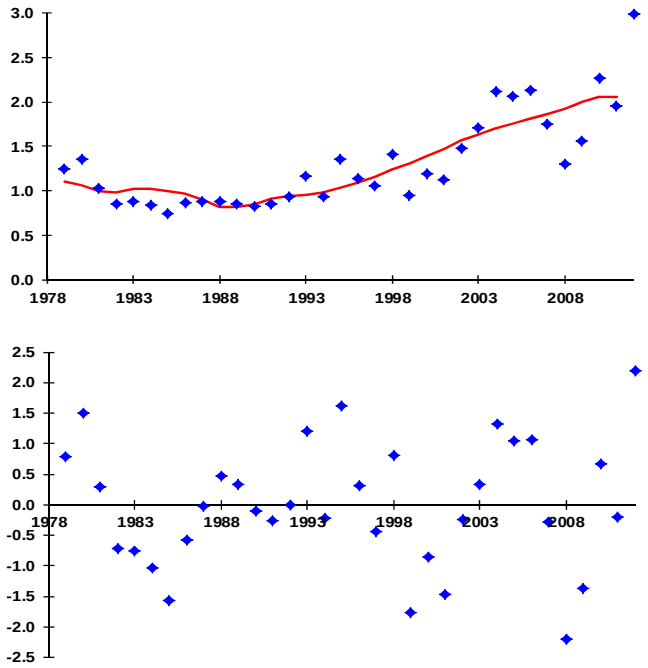

Figure 12: Surplus production model observation error fit: CPUE in kg/pot (upper) from the base case MPD: diamonds are the observed and the line is the predicted CPUE; and residuals from the fit (lower).

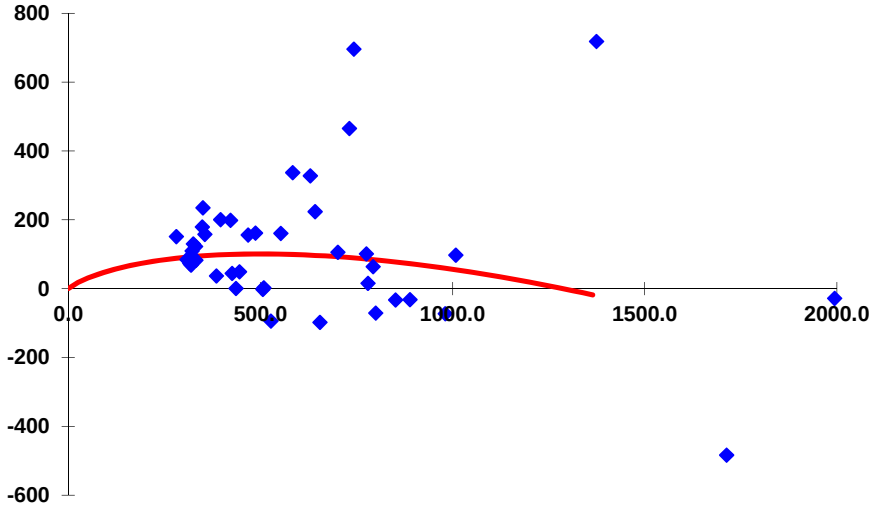

Figure 13: Surplus production model observation error fit: observed (diamonds) and predicted production (line) versus biomass.

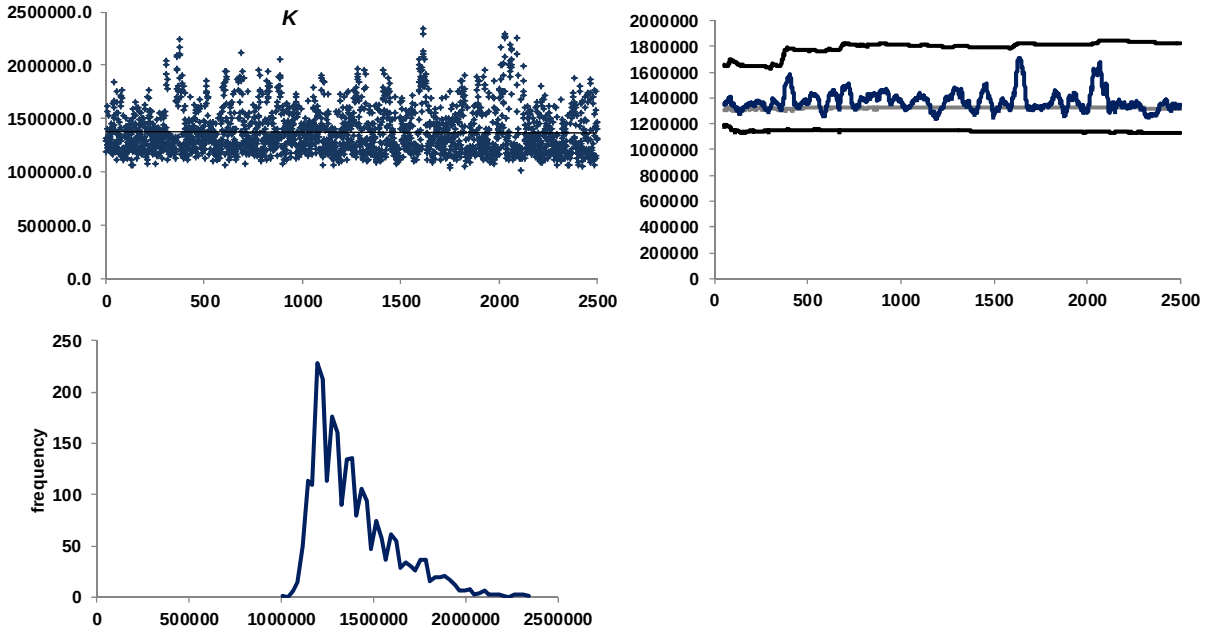

Figure 14: Surplus production model observation error fit: diagnostic plots for *K* (in kg): top left shows the McMC trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

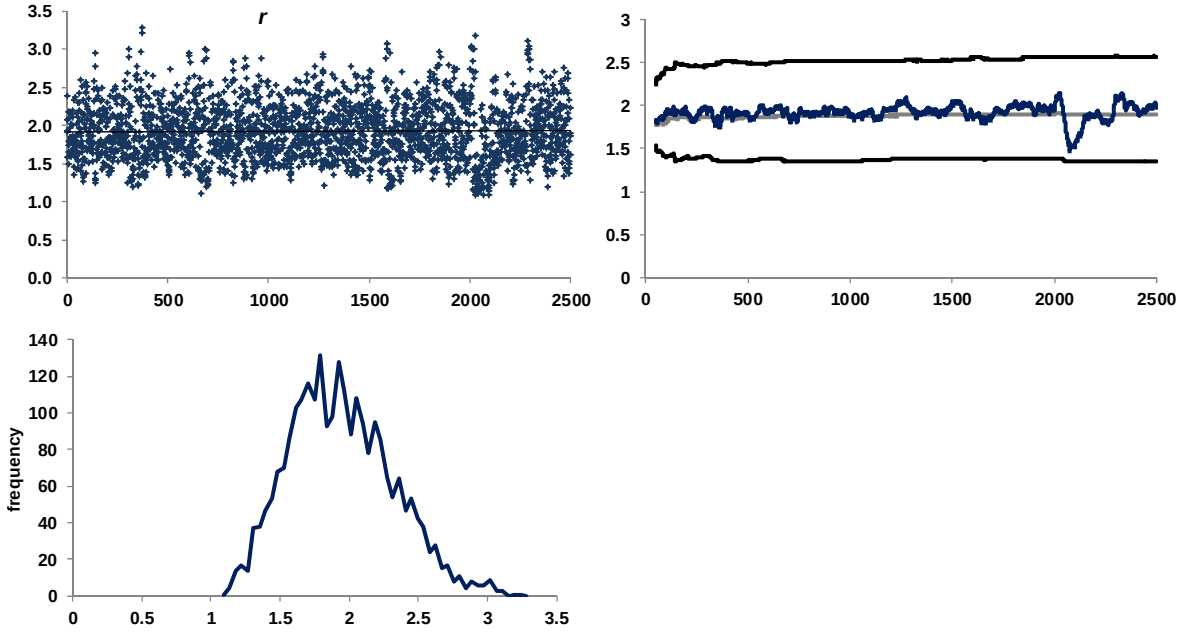

Figure 15: Surplus production model observation error fit: diagnostic plots for *r*: top left shows the trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

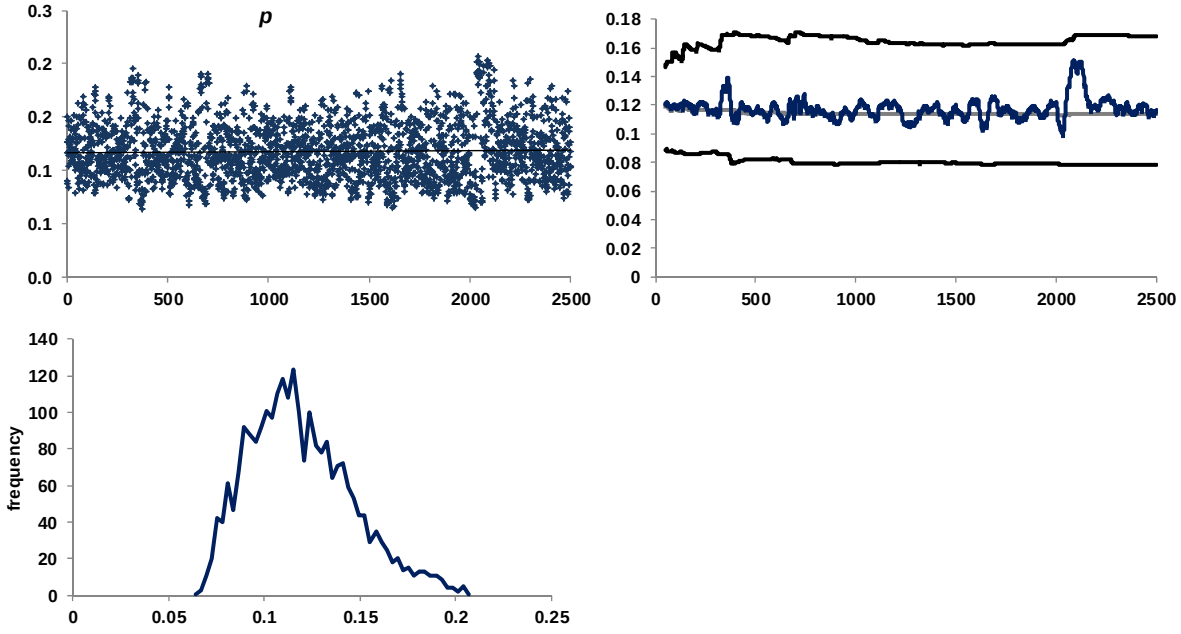

Figure 16: Surplus production model observation error fit: diagnostic plots for *p*: top left shows the trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

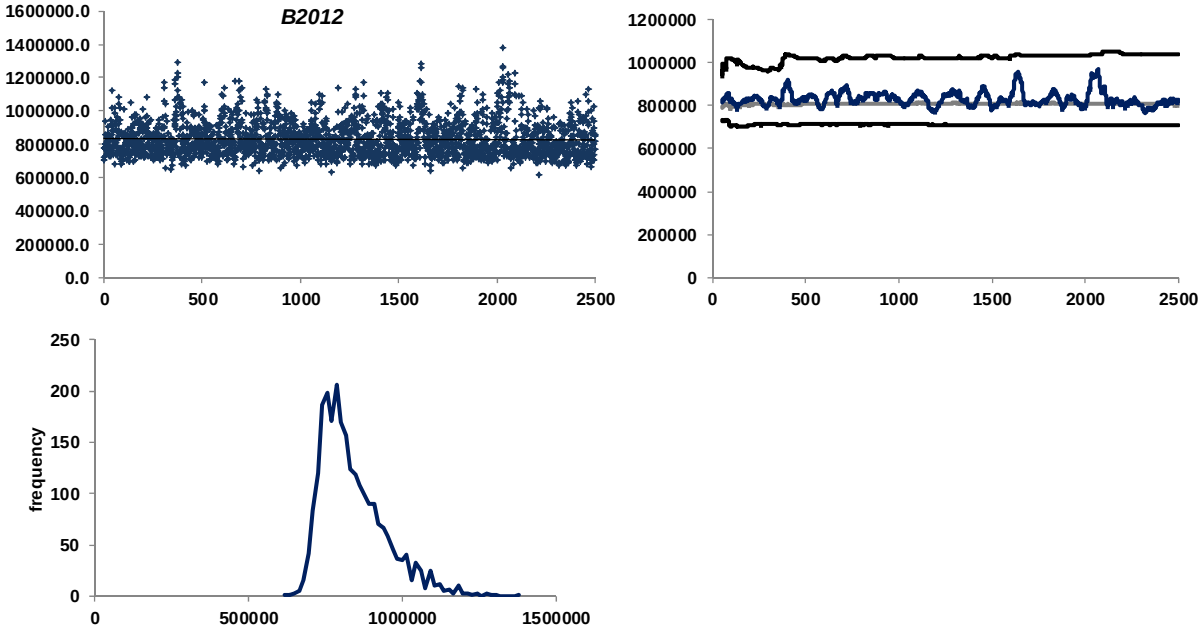

Figure 17: Surplus production model observation error fit: diagnostic plots for 2012 biomass (in kg): top left shows the trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

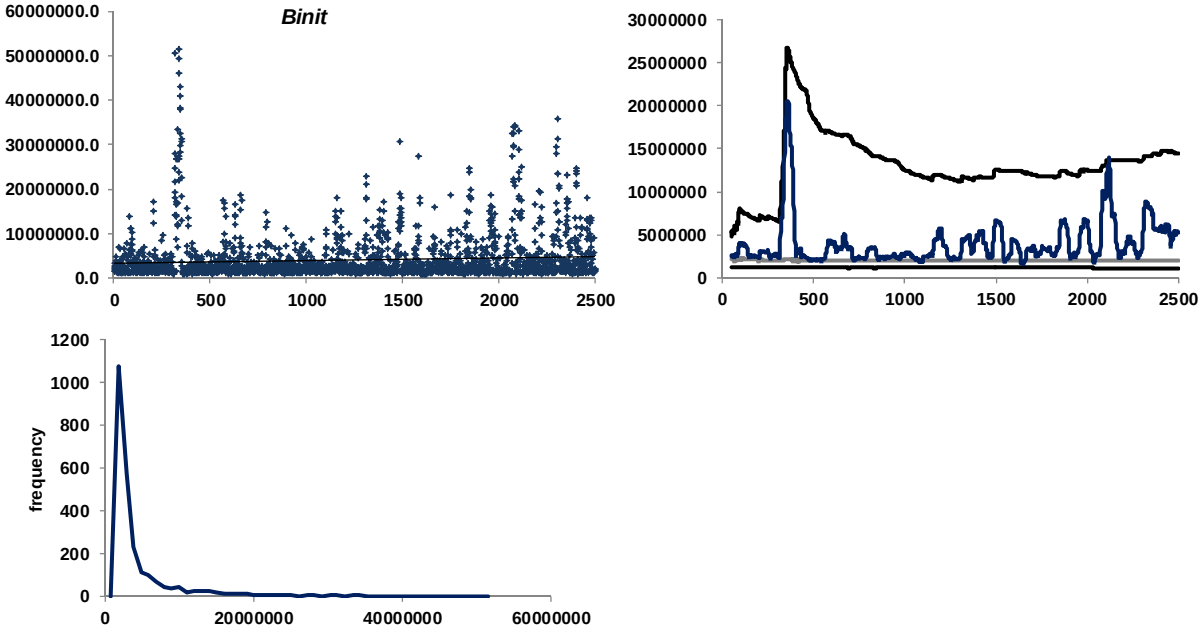

Figure 18: Surplus production model observation error fit: diagnostic plots for *Binit* (in kg): top left shows the trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

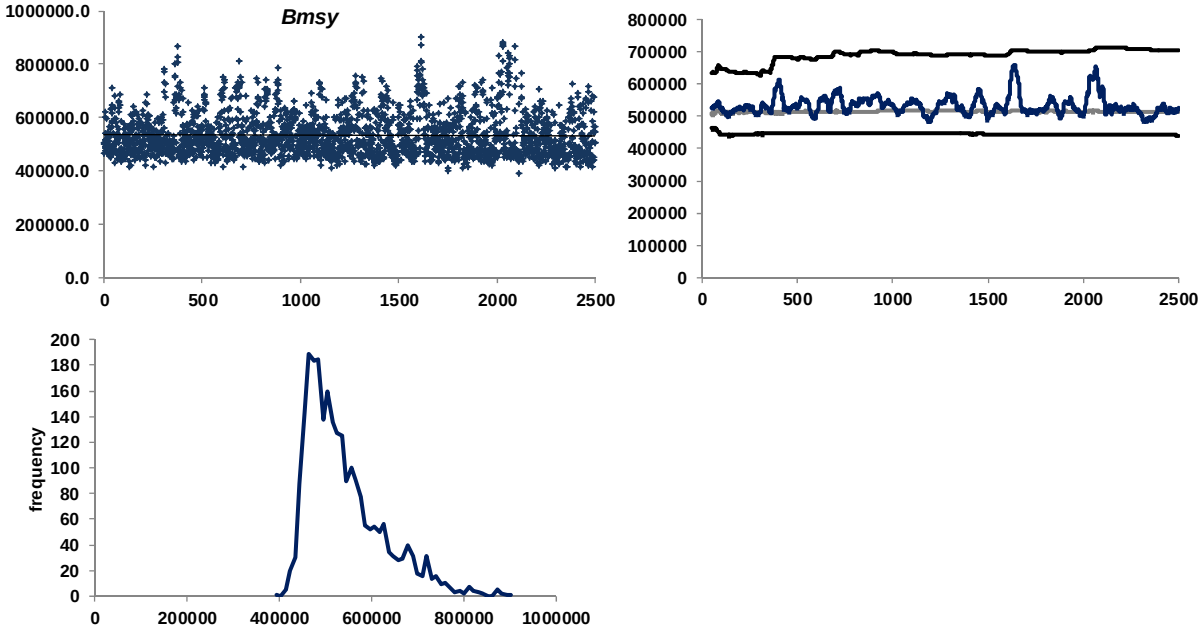

Figure 19: Surplus production model observation error fit: diagnostic plots for *Bmsy* (in kg): top left shows the trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

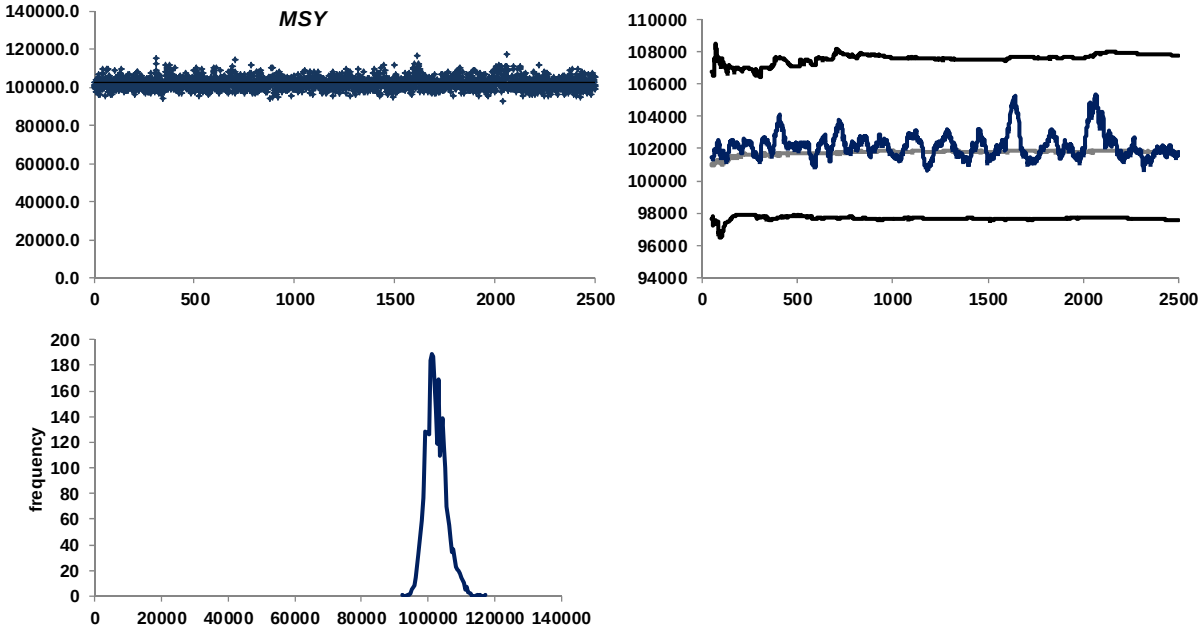

Figure 20: Surplus production model observation error fit: diagnostic plots for *MSY* (in kg): top left shows the trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

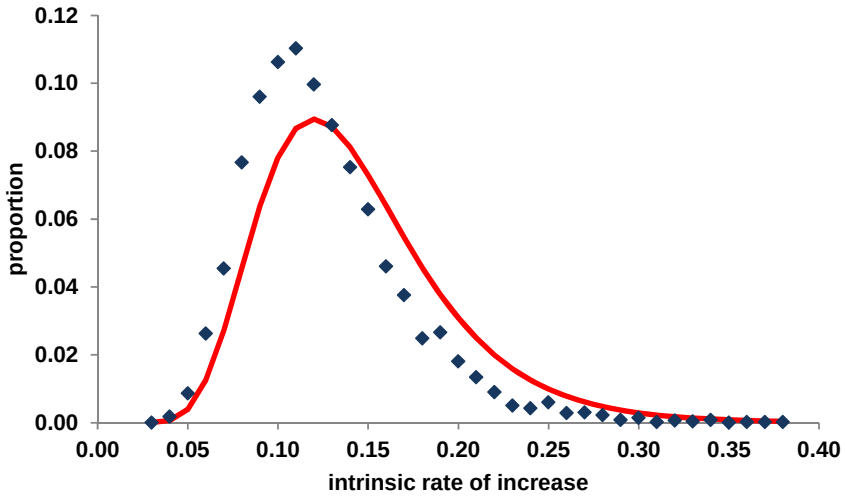

Figure 21: Observation error fit: comparing the posterior distribution of the intrinsic rate of increase (blue diamonds) with the prior (red line).

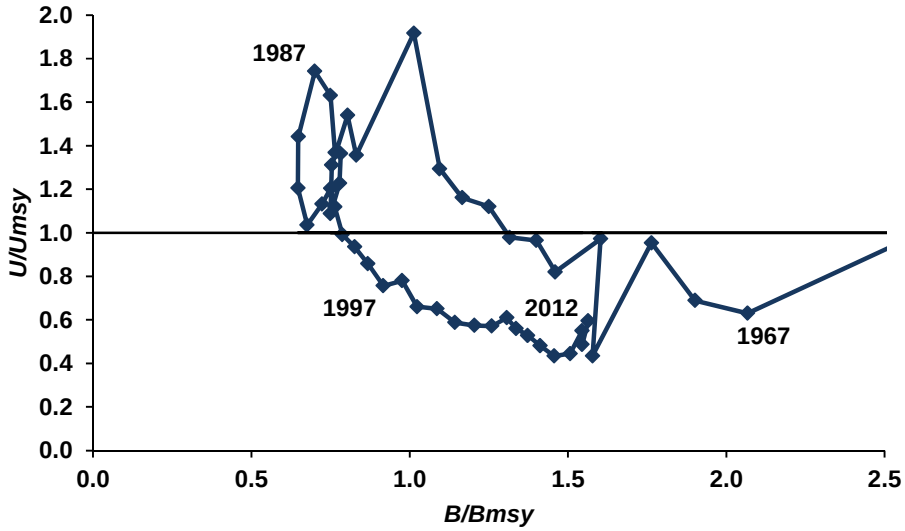

Figure 22: Observation error fit: Snail trial of the CRA 9 fishery: the x-axis is the mean of the posterior distribution of biomass as a proportion of *Bmsy*; the y-axis is the mean of the posterior of exploitation rate as a proportion of equilibrium exploitation rate at *Bmsy*; the horizontal line is 1.0 (equilibrium exploitation rate at *Bmsy*).

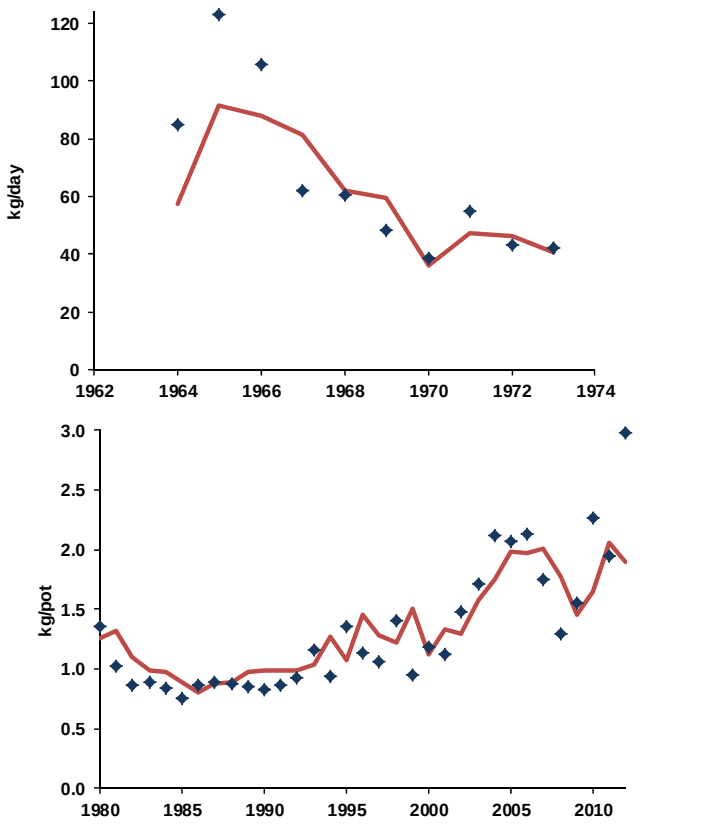

Figure 23: Surplus production model process error fit: fit to CPUE in kg/day (upper) and kg/pot (lower) from the base case MPD fit: diamonds are the observed and the line is the predicted CPUE.

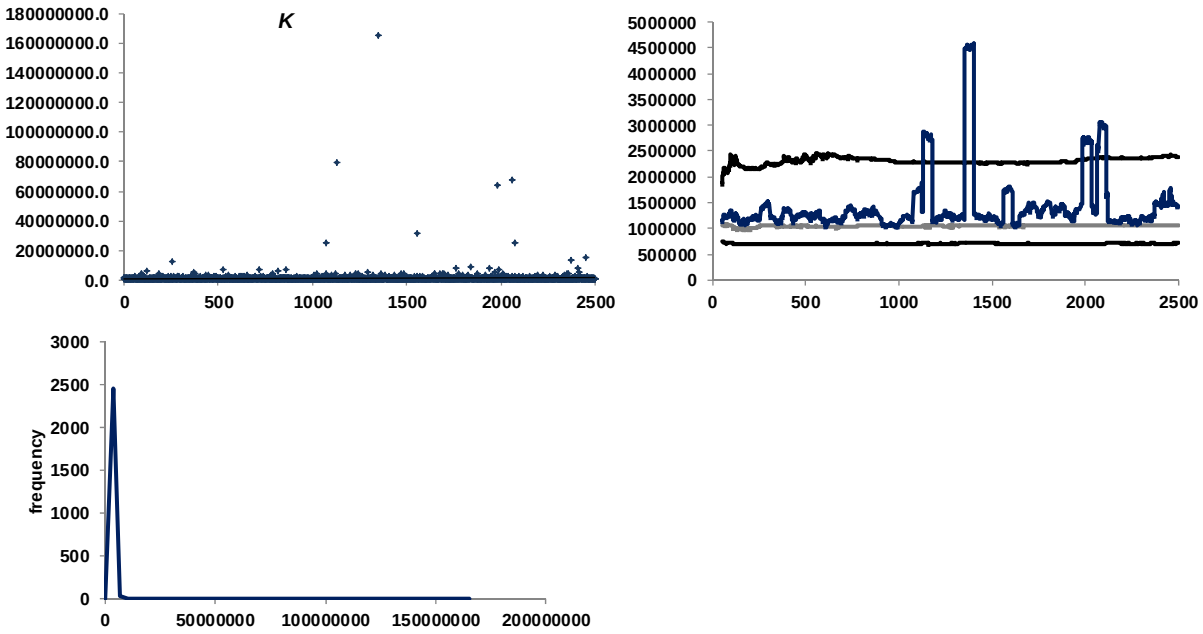

Figure 24: Surplus production model process error fit: diagnostic plots for *K* (in kg): top left shows the McMC trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

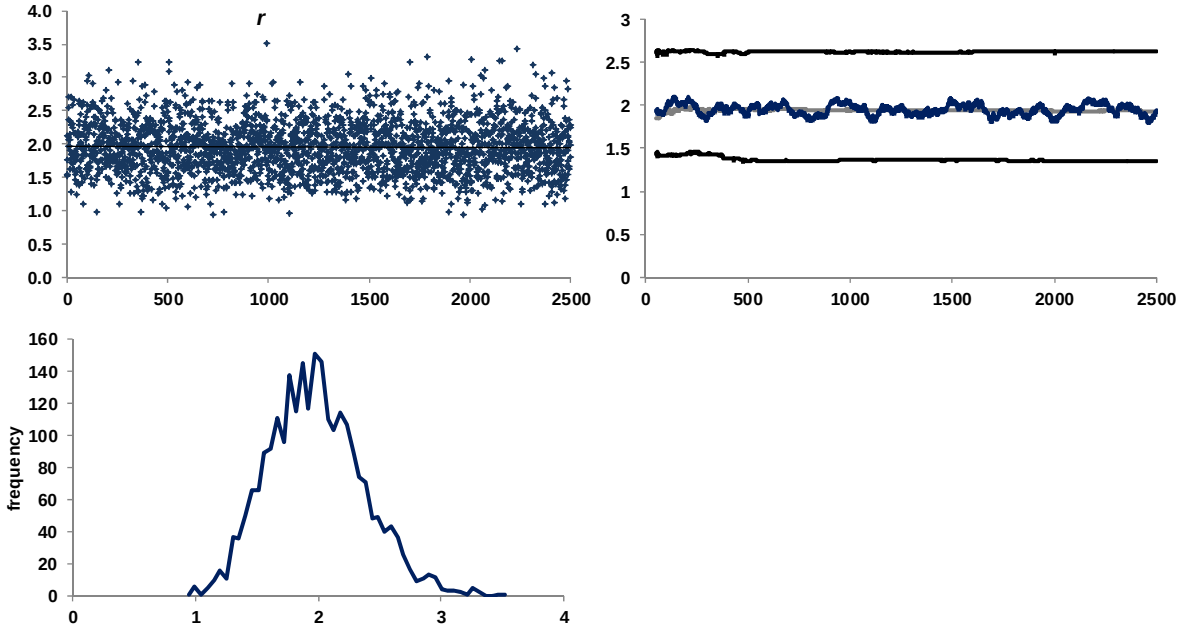

Figure 25: Surplus production model process error fit: diagnostic plots for *r*: top left shows the McMC trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (grey line); the bottom plot shows the posterior distribution.

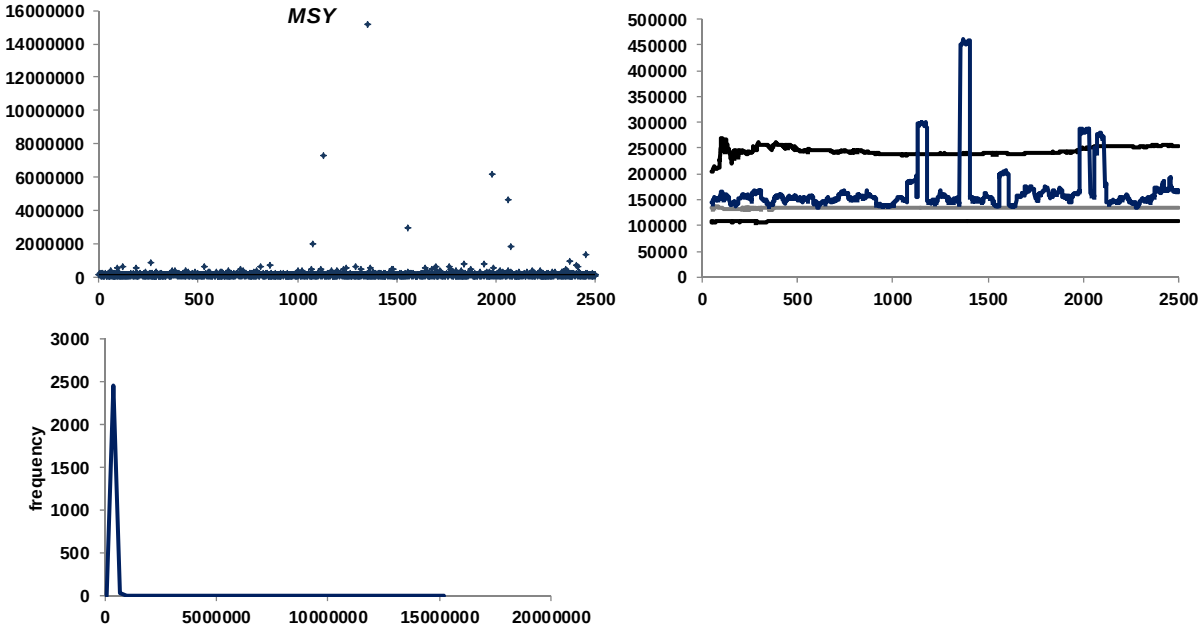

Figure 26: Surplus production model process error fit: diagnostic plots for *Bmsy* (in kg): top left shows the McMC trace and a trend line; top right shows a running median with 5th and 95th quantiles (black lines) and a moving average over 50 samples (blue line); the bottom plot shows the posterior distribution.

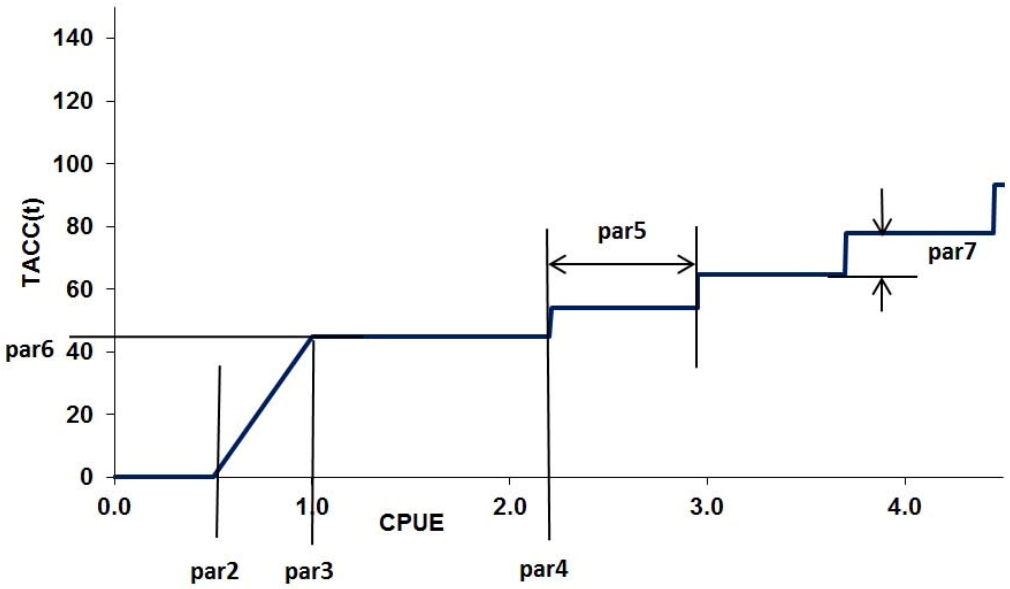

Figure 27: The generalised TACC step rule, showing the six parameters that define its shape.

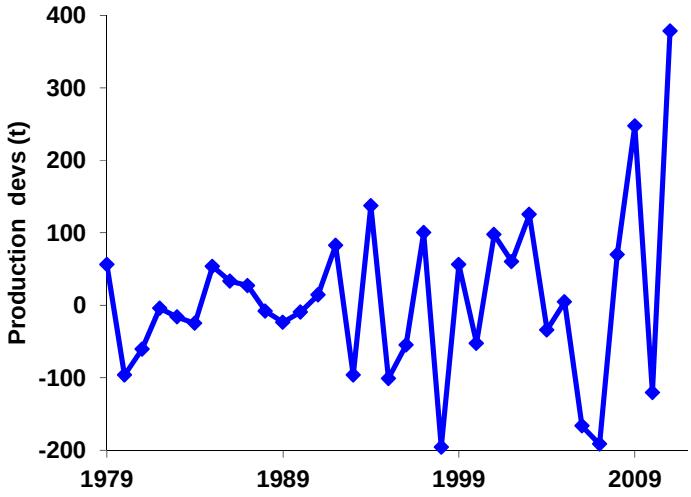

Figure 28: Production deviations from the MPD of the observation error base case model.

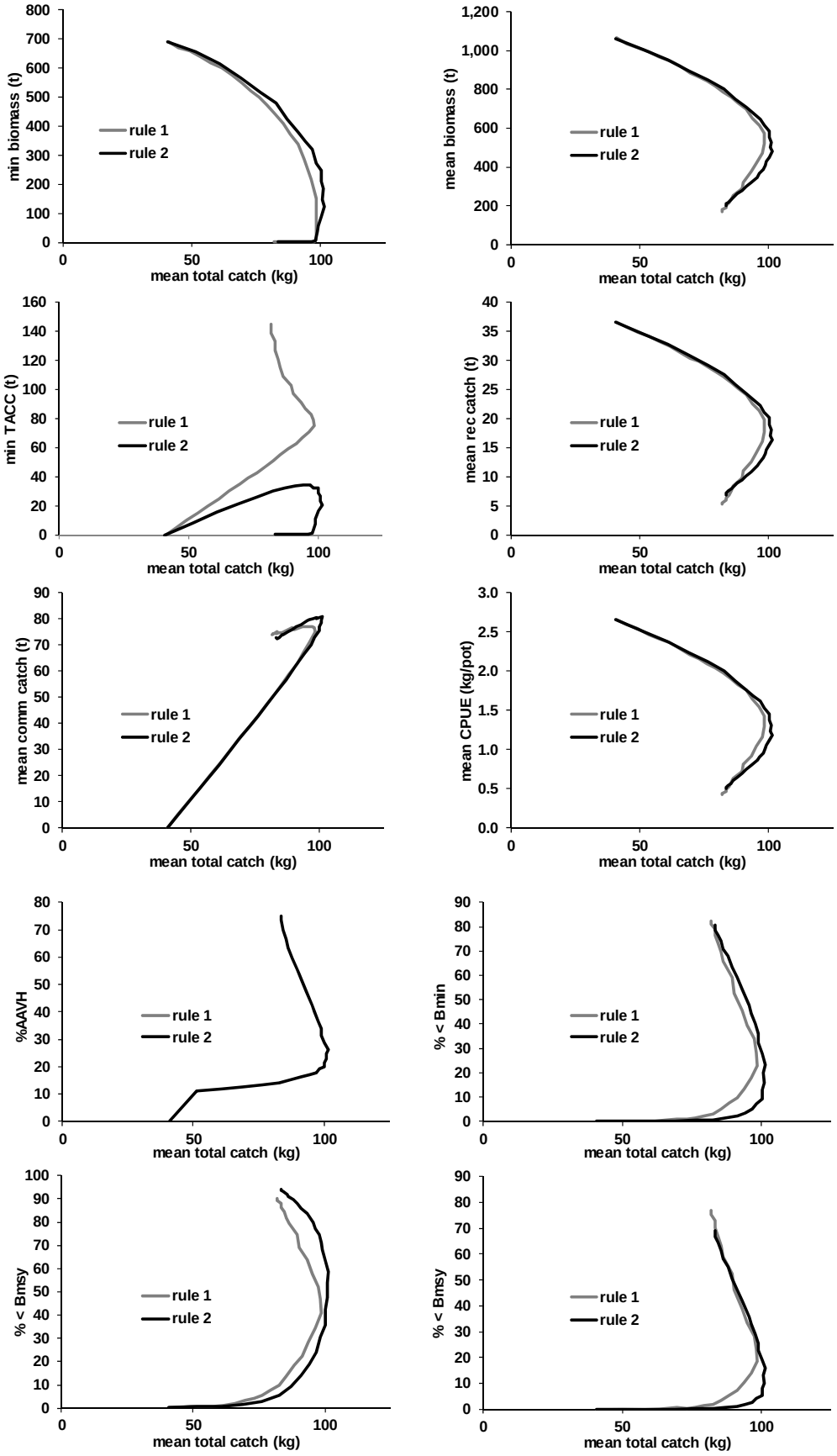

Figure 29: Some indicator summaries from preliminary explorations with the base case operating model using rule 1 with constant TACs (grey line) and rule 2 with CPUE multipliers (black).

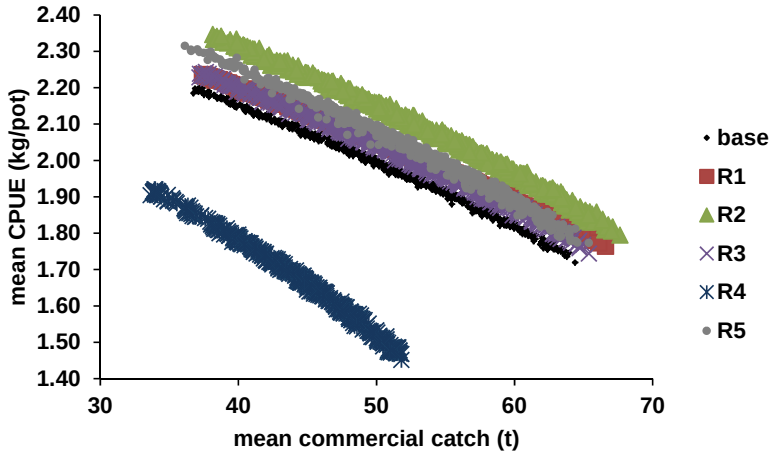

Figure 30: Average CPUE versus average commercial catch in the 619 harvest control rules that met safety thresholds in the base case and five robustness trials.

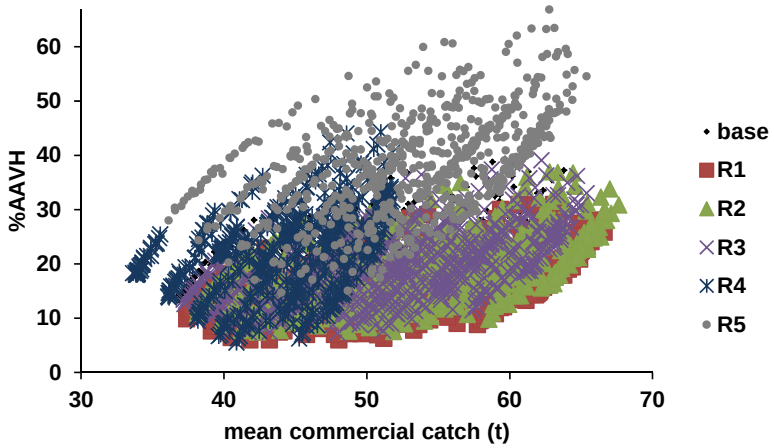

Figure 31: Average AAVH versus average commercial catch in the 619 harvest control rules that survived safety criteria screening in the base case and five robustness trials.

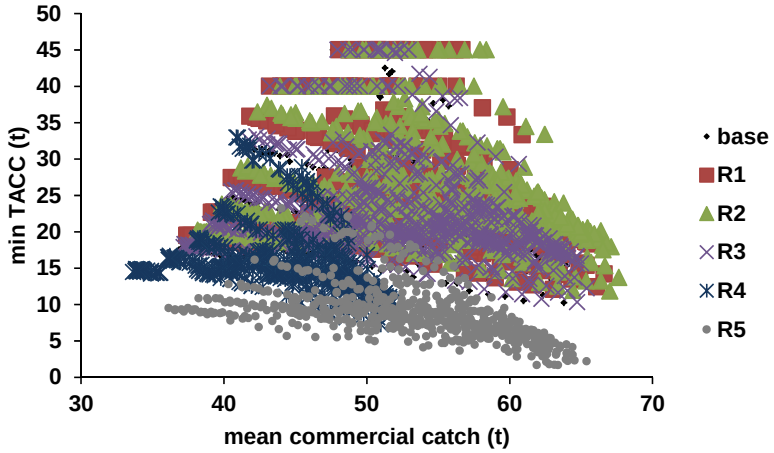

Figure 32: Average minimum TACC versus average commercial catch in the 619 harvest control rules that survived safety criteria screening in the base case and five robustness trials.

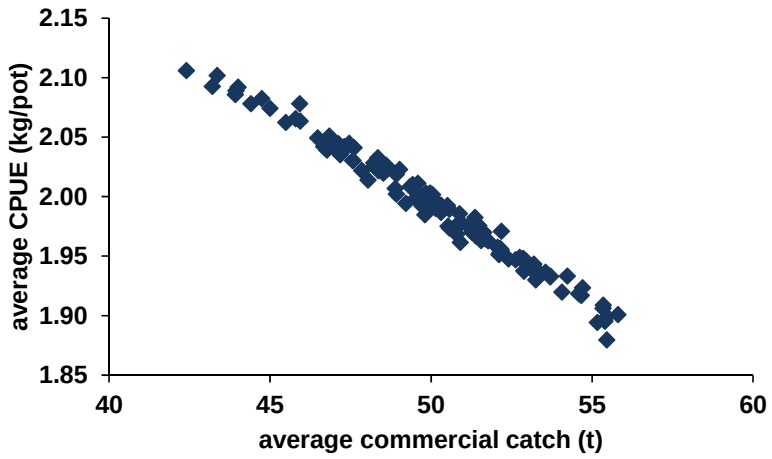

Figure 33: In the screened set of 112 candidate rules, the trade-off between average commercial catch and average CPUE.

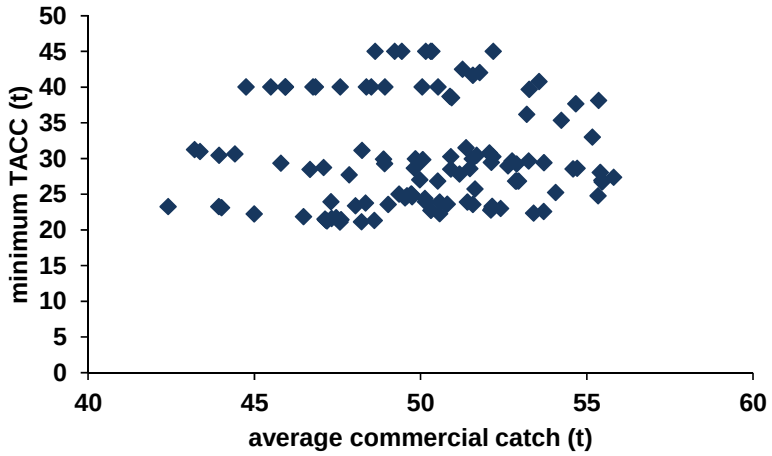

Figure 34: In the screened set of 112 candidate rules, the trade-off between average commercial catch and minimum TACC.

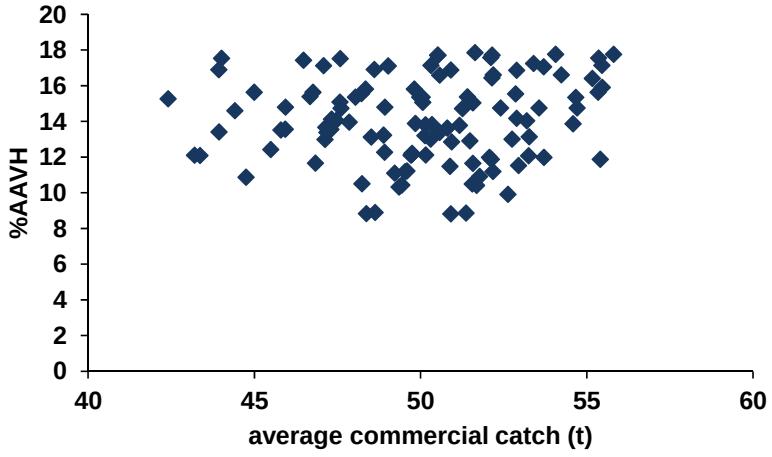

Figure 35: In the screened set of 112 candidate rules, the trade-off between average commercial catch and %AAVH.

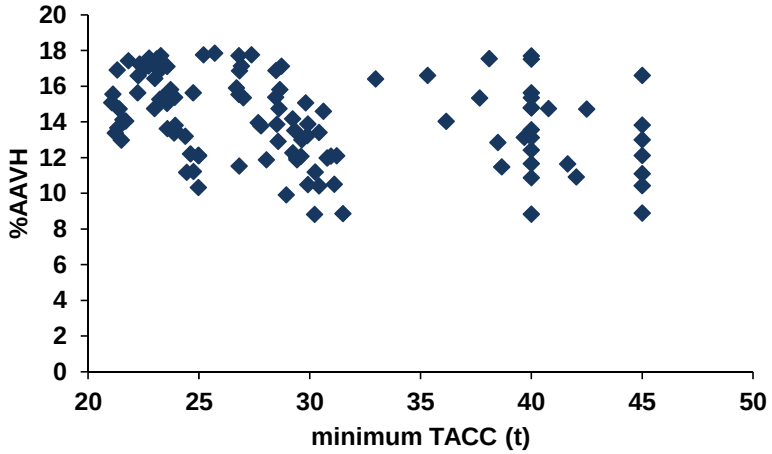

Figure 36: In the screened set of 112 candidate rules, the trade-off between minimum TACC and %AAVH.

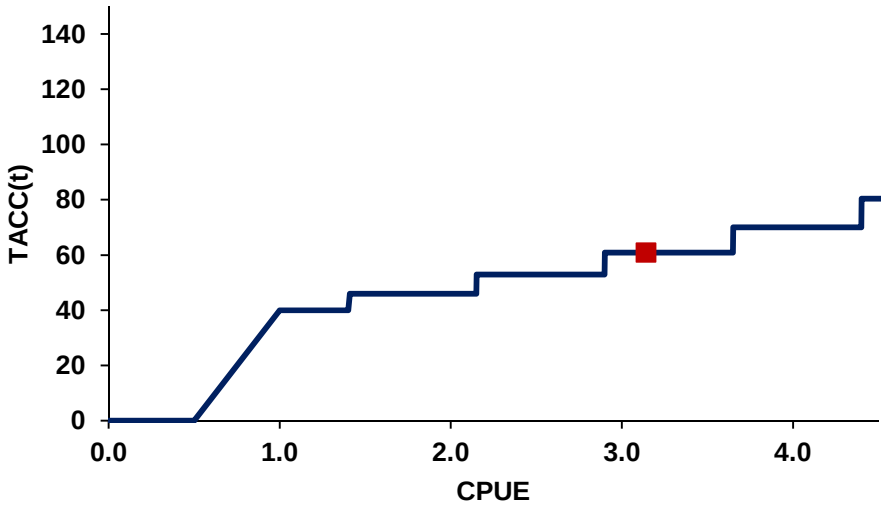

Figure 37: Rule 4041: the red square indicates the TACC at the 2013 level of CPUE.

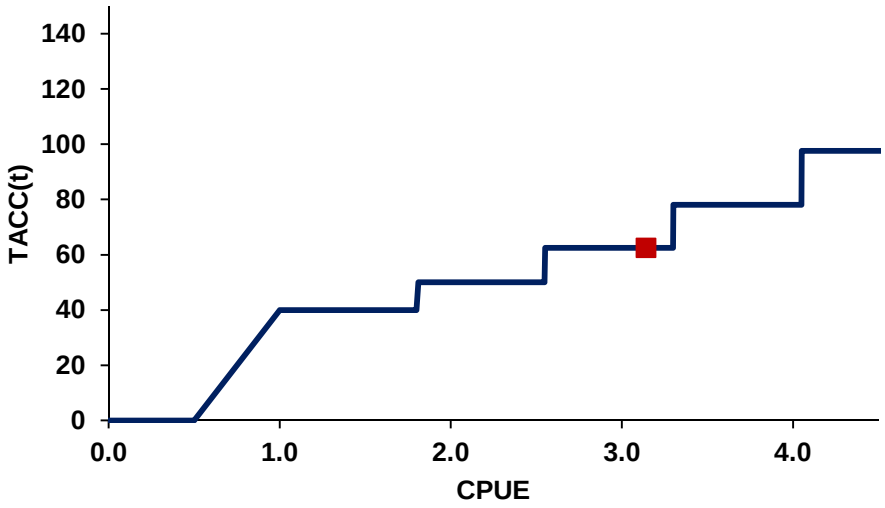

Figure 38: Rule 4103: the red square indicates the TACC at the 2013 level of CPUE.

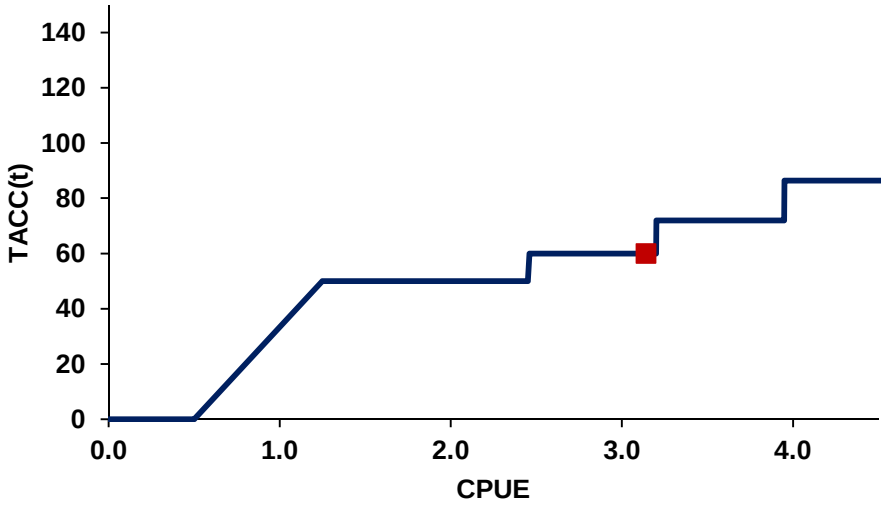

Figure 39: Rule 4346: the red square indicates the TACC at the 2013 level of CPUE.

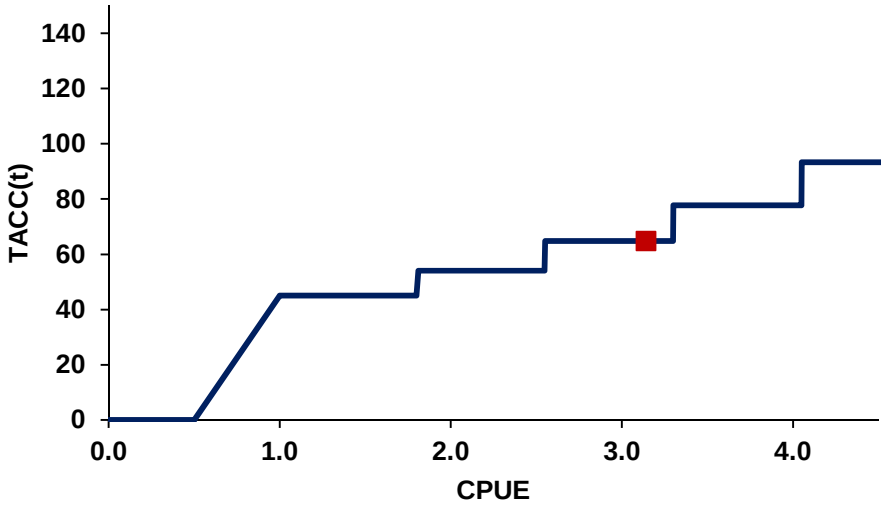

Figure 40: Rule 4942: the red square indicates the TACC at the 2013 level of CPUE.

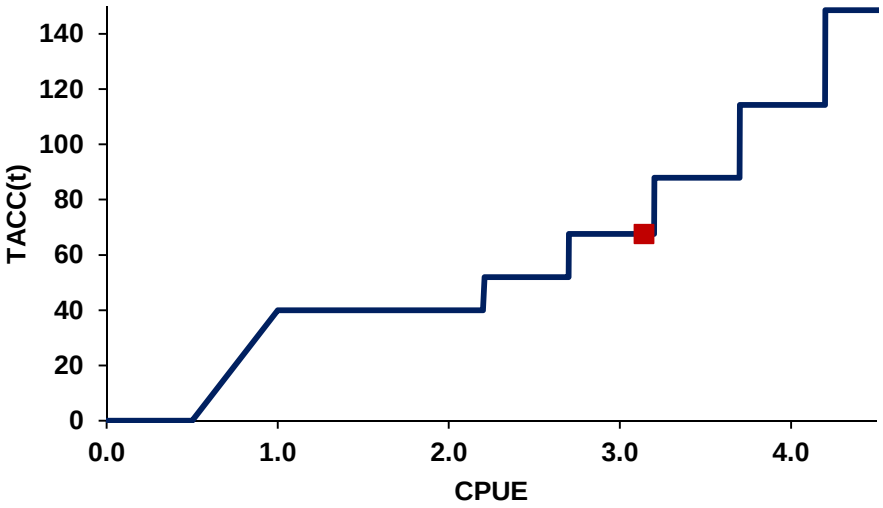

Figure 41: Rule 4144: the red square indicates the TACC at the 2013 level of CPUE.

APPENDIX A: CRA 9 LENGTH FREQUENCY DATA

These length frequency (LF) data, from CRA 9 logbooks, were compiled as part of the CRA 9 characterisation presented to the RLFAWG in June 2013. Data were obtained from Nokome Bentley in August 2012 for each QMA that had substantial logbook programmes, including CRA 9. The period covered by these data was 1993–94 through 2011–12.

Fields in the extract were:

- an anonymous fisher ID, which appeared to be originally sequential except for the last three fishers
- fishing year (following the naming convention by which "2006–07" is called "2006")
- calendar month
- statistical area
- sex (these sex codes differ from the observer catch sampling sex codes):
    - 1 - male
    - 2 - immature female
    - 3 - mature female
    - 4 - berried female
    - 5 - spent female
- tail width (TW) (mm rounded down)
- caught: total measured for each ID/year/month/stat area/sex/TW cell
- retained: total retained for each cell.

CRA 9 data were extracted by choosing Statistical Areas 930, 930, 935, 936 and 937. Area 929, which straddles CRA 8 and CRA 9 (see Figure 1), was not included. A small number of records with TW = 0 were deleted, leaving 7020 records with 22 561 fish measured. One fish was below 30 mm TW and was not plotted.

A summary of the data is shown in Table A1. Data were available from 1996 to the present, with years 2002–04 missing. Logbook participants were very sparse in the beginning, but there were four to five in all years from 2005–11. Numbers of fish measured were low in the early years but have averaged 2500 since 2005. The sex ratio is skewed slightly towards females but is reasonably balanced.

Mean tail width decreased to 2001 and has been increasing since 2005 (Table A1, Figure A1).
Mean weight of the legal-sized catch (but including berried females, which are not legal) showed a similar pattern (Figure A2). When berried females were excluded, mean legal weights were considerably higher (Table A1) and these also increased since 2005.

Figure A3 shows the LFs for each year, with all females codes combined.

Table A1: CRA 9: Numbers of fish measured by sex in the logbook program, number of participating fishers, mean size (mm TW) and mean weight (kg) of legal fish excluding berried females.

	Sex code							Mean length	Mean length	Mean
Year	1	2	3	4	5	Total	IDs	male	female	weight
1996	133		2	73	1	209	1	74.5	74.6	
1997	117	2		147		266	1	78.1	79.2	
1998	323	14	55	206	8	606	3	72.9	70.0	
1999	72	15	122	11		220	1	75.1	68.1	
2000	452	146	125	482	6	1 211	3	65.3	66.8	
2001	668	182	207	698	24	1 779	3	60.1	70.4	
2005	1 056	60	65	747	2	1 930	4	73.4	76.4	1.31
2006	1 314	5	67	1 236	6	2 628	5	72.3	74.2	1.24
2007	1 747	13	330	1 328	55	3 473	4	78.4	76.2	1.41
2008	1 242	1	983	1 027	81	3 334	5	80.7	81.6	1.53
2009	1 401	1	1 194	1 167	9	3 772	4	83.9	80.1	1.72
2010	746		5	525		1 276	4	85.0	75.6	2.29
2011	790	1	360	703	3	1 857	4	81.3	76.6	1.92
Total	10 061	440	3 515	8 350	195	22 561	12			

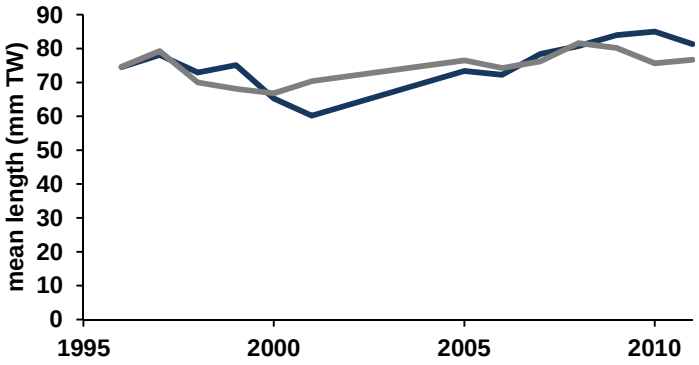

Figure A1: CRA 9: Mean tail width of males (dark blue) and females (grey).

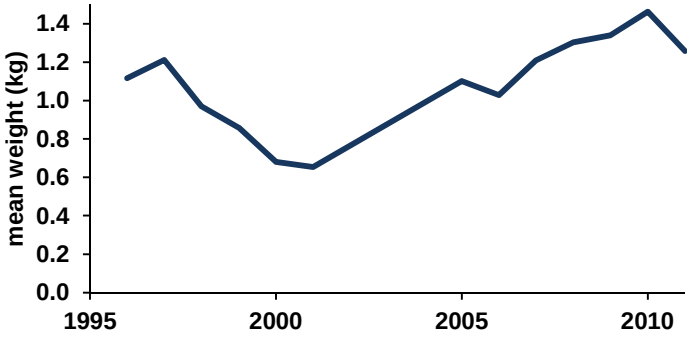

Figure A2: CRA 9: Mean weight of legal males and females combined; this includes berried females.

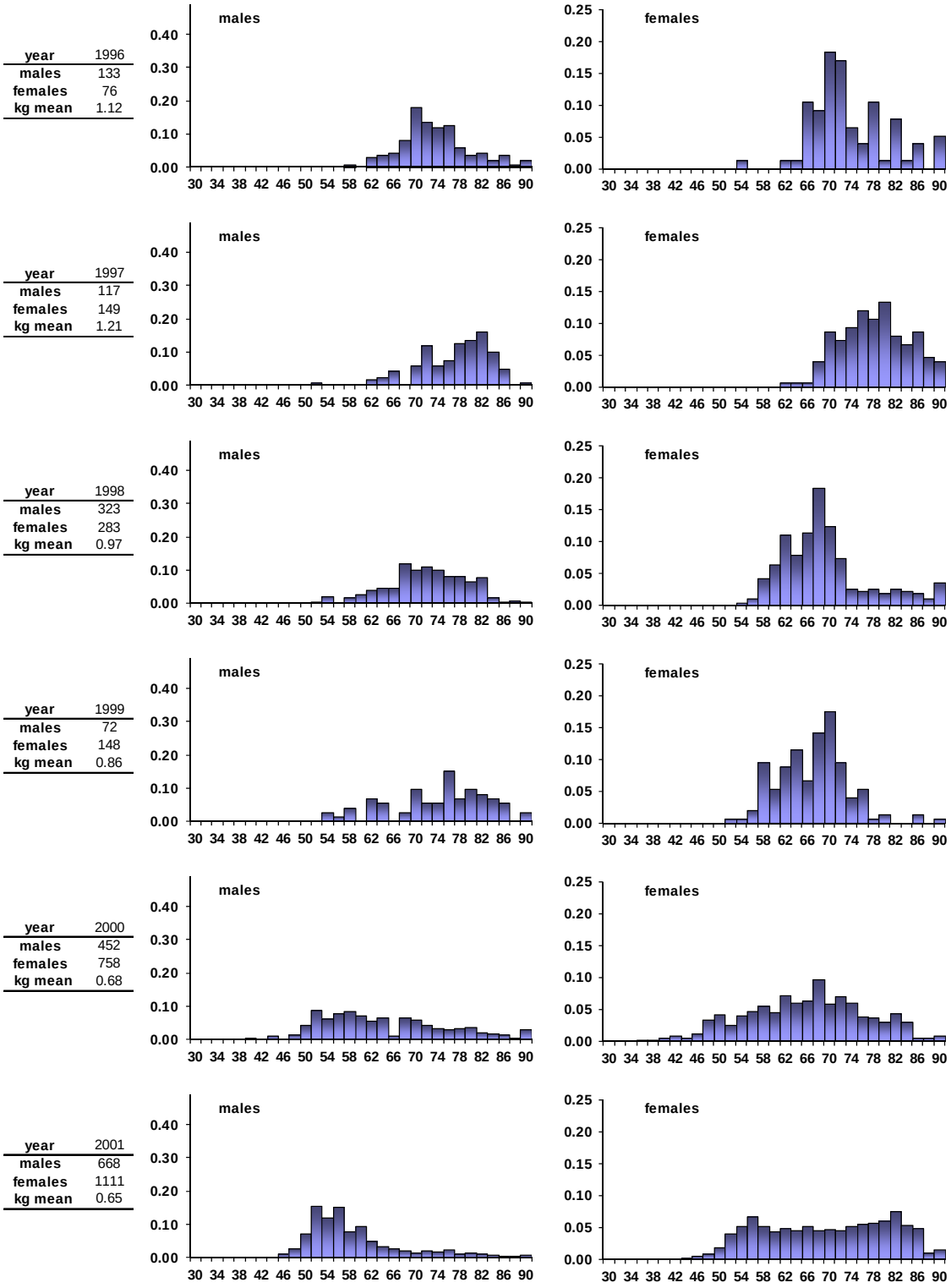

Figure A3: LFs from CRA 9 by sex, in 2-mm TW bins. Fish larger than 91 mm are binned in the last bin. Information at left gives the year, sample size of males and females and mean weight of legal fish.

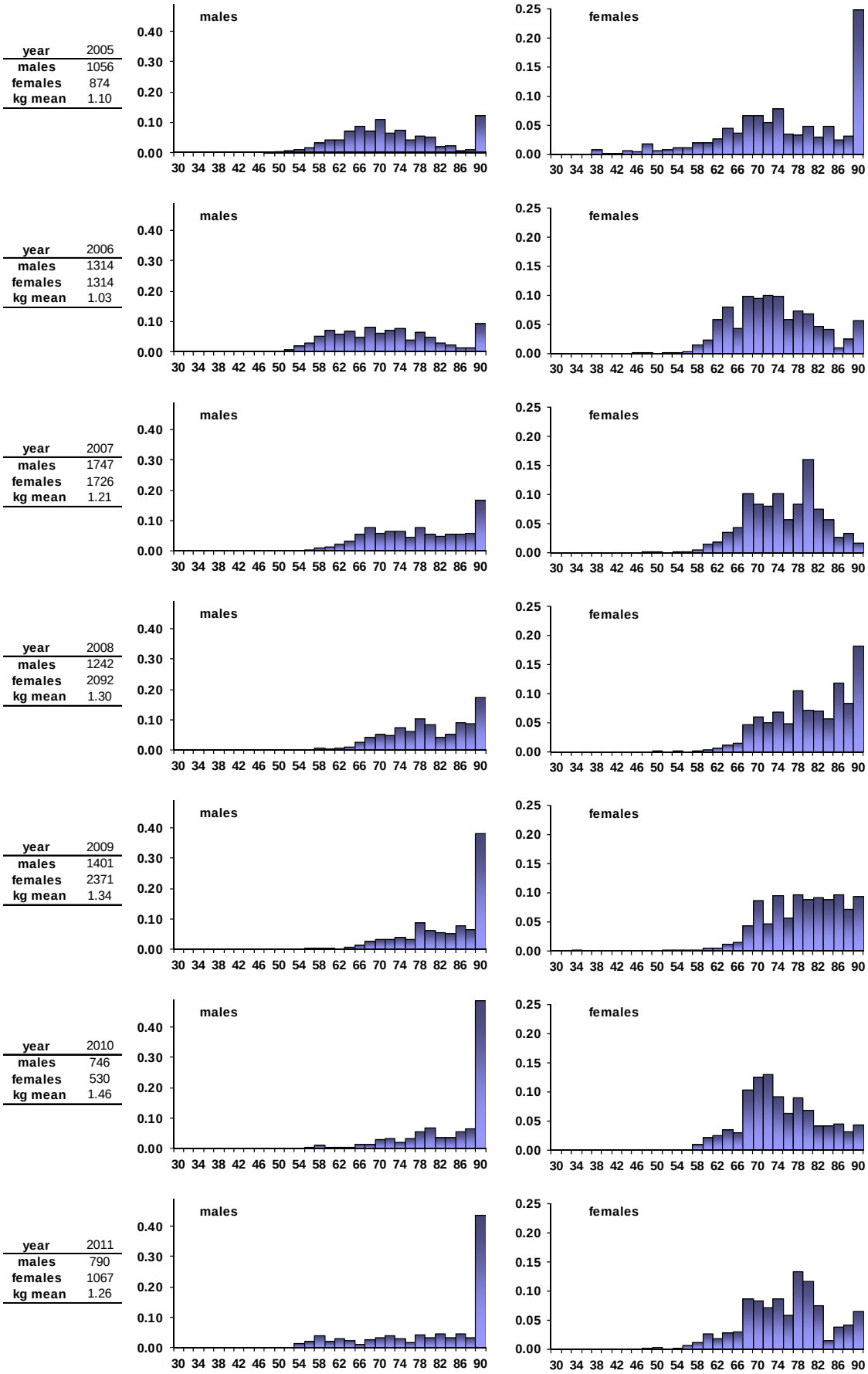

Figure A3 concluded.

APPENDIX B: RETENTION-AT-SIZE

Because of differential grade prices, legal high-grading is a feature of some fisheries that have high catch rates. Fishers put big lobsters back into the sea and wait to catch smaller lobsters that are worth more per unit weight. Beginning in 2012, this part of the fishing dynamics was incorporated into the stock assessment model (Haist et al. 2013), and retention curves were estimated for CRA 8 from logbook data (Starr et al. 2013).

The analyses shown here were presented to the RLFAWG in June 2013 as part of the CRA 9 characterisation. Data used were those described in Appendix A.

When gross retention was calculated by year as total number of lobsters measured divided by total number retained, it was clear that retention was not recorded reliably before 2005 (Table B1); accordingly, records before the 2005 fishing year were removed, leaving 5171 records with 18 270 measurements from seven fishers.

A legal code was assigned as 0 or 1. The code was zero for:

- males smaller than 54 mm TW
- all berried females
- all other females less than 60 mm TW.

Table B1: CRA 9: Numbers caught (measured), numbers retained and the overall percentage retention by year.

8.1.1.1	Year	8.1.1.2	Caught	8.1.1.3	Retained	%retained
	1996		209		0	0%
	1997		266		0	0%
	1998		606		0	0%
	1999		220		0	0%
	2000		1 211		35	3%
	2001		1 779		345	19%
	2005		1 930		1 058	55%
	2006		2 628		1 323	50%
	2007		3 473		1 890	54%
	2008		3 334		2 144	64%
	2009		3 772		2 169	58%
	2010		1 276		674	53%
	2011		1 857		817	44%
	Total		22 561		10 455	46%

Retention rates of legal males (Table B2) were about 88%, but spent females were less than half that. Most non-legal fish were berried females, and the retention rate of non-legal fish was only 0.4%.

Table B2: CRA 9: Retention by sex and legality (0 illegal; 1 legal) for years 2005–11.

Sex	Code	Legal	Caught	Retained	%retained
Male	1	0	42	4	9.5%
	1	1	8 254	7 153	86.7%
Immature female	2	0	71	0	0.0%
	2	1	10	2	20.0%
Mature female	3	0	9	1	11.1%
	3	1	2 995	2 829	94.5%
Berried female	4	0	6 733	24	0.4%
	4	1			
Spent female	5	0	3	0	0.0%
	5	1	153	62	40.5%
Total		0	6 858	29	0.4%
		1	11 412	10 046	88.0%

After the data were restricted further to the legal animals (3218 records with 11 412 measurements), differences were explored by fisher and sex (Table B3). Total numbers measured across all years varied from 161 to 4082, averaging 1630. Gross retention by fishers varied from 83% to 99%, averaging 92% across fishers and 88% of fish overall.

Legal fish measured were 72% male, 26% mature female, with almost no immature females and 1% spent. Three IDs never measured a spent female. Retention of spent females was variable, but the numbers were too low to support analysis.

Table B3: CRA 9: Retention of legal fish by fisher ID and sex: C indicates number caught and %R indicates percent retained.

			Female							
	Male		Immature		Mature		Berried		Total	
ID	C	%R	C	%R	C	%R	C	%R	C	%R
213	533	96%			1	0%	1	100%	535	96%
243	750	97%			3	100%			753	97%
255	2 568	79%	6	33%	1 450	94%	58	0%	4 082	83%
256	1 862	81%	3	0%	1 119	98%	13	0%	2 997	87%
260	1 899	93%	1	0%	322	92%			2 222	93%
261	159	99%			2	100%			161	99%
274	483	91%			98	76%	81	75%	662	87%
Total	8 254	87%	10	20%	2 995	94%	153	41%	11 412	88%

Retention was explored for each ID by year and month to identify any obvious problems; for no ID could any obvious problem could be seen. The minimum and maximum retention by cell, and the prevalence of cells with 100% retention, are shown in Table B4. All IDs were used in the analyses below.

Table B4: CRA 9: By fisher ID, years of logbook data in 2005–11, number of legal fish measured, minimum and maximum percentage retention in a month, number of months and the percentage of months with 100% retention.

ID	Years	Fish	Min.	Max.	Months	100% prevalence
213	2	535	98%	100%	5	40%
243	2	753	86%	99%	6	0%
255	7	4082	54%	100%	32	3%
256	7	2997	34%	100%	29	28%
260	7	2222	57%	100%	27	22%
261	1	161	98%	100%	22	50%
274	4	662	60%	100%	16	13%

The number of IDs reporting was similar among years (Table B5). Retention of males was 95% or higher in 2005–06, then dropped to about 91%, and was much lower in 2009 and 2011. With much smaller sample sizes, female retention rates showed no pattern over time. In September, the 2012 logbook data were analysed separately, and showed decreasing logbook participation and decreasing retention of males.

Table B5: CRA 9: Numbers fishers reporting, legal fish measured by sex and percent retained by year.

Year	IDs	Male	%retained	Female	%retained	Total
2005	4	1 041	95%	65	94%	1 106
2006	5	1 299	97%	72	86%	1 371
2007	4	1 741	91%	388	80%	2 129
2008	5	1 240	93%	1 063	92%	2 303
2009	4	1 400	72%	1 203	95%	2 603
2010	4	746	90%	5	100%	751
2011	4	787	62%	362	91%	1 149
Total		8 254	87%	3 158	92%	11 412
2012	2	586	44%	629	96%	1 215

Retention by size is shown by year for males and females in Figures B1 and B2 respectively, with the data in 2-mm bins. Retention curves were fitted with either the logistic or the inverse logistic, whichever fitted, with weighted non-linear least squares (Tables B6 and B7), excluding any cells with fewer than 10 fish observed. For males (Figure B1), maximum retention decreased with time. For 2005–08, the curves were logistic, indicating increasing retention with increasing size. The curve was flat for 2008. For 2009–11, the inverse logistic fitted, indicating decreasing retention with increasing size. For 2009–11, the point at which the curve begins to decline steeply is much larger than the analogous points in CRA 8.

Table B6: CRA 9: Males: estimated parameters for the logistic (with parameter L95–50) or inverse logistic (with L50–95) curves describing retention as a function of size.

Year	Max.	L50	L95–50	L50–L95	SS
2005	1.000	22.7	45.7		0.57
2006	0.984	0.0	54.3		1.20
2007	0.906	0.0	96.5		13.75
2008	0.933	431 365.8		482 063.4	10.55
2009	0.970	97.7		14.4	8.77
2010	0.943	112.8		14.9	3.24
2011	0.883	102.5		5.7	5.56

For females, seeing a pattern is hampered by the low numbers (Table B7). For three years there were too few females for curves to be fitted (Table B5). The curves (Figure B2) suggest that smaller females are retained at lower rates than larger females, but there was no apparent pattern over time.

Table B7: CRA 9: Females: estimated parameters for the logistic curves describing retention as a function of size.

Year	Max.	L50	L95-50	SS
2005				
2006				
2007	1.000	47.0	51.7	2.61
2008	0.964	62.8	15.9	2.29
2009	1.000	50.1	29.5	0.42
2010				
2011	0.961	67.0	4.1	1.11

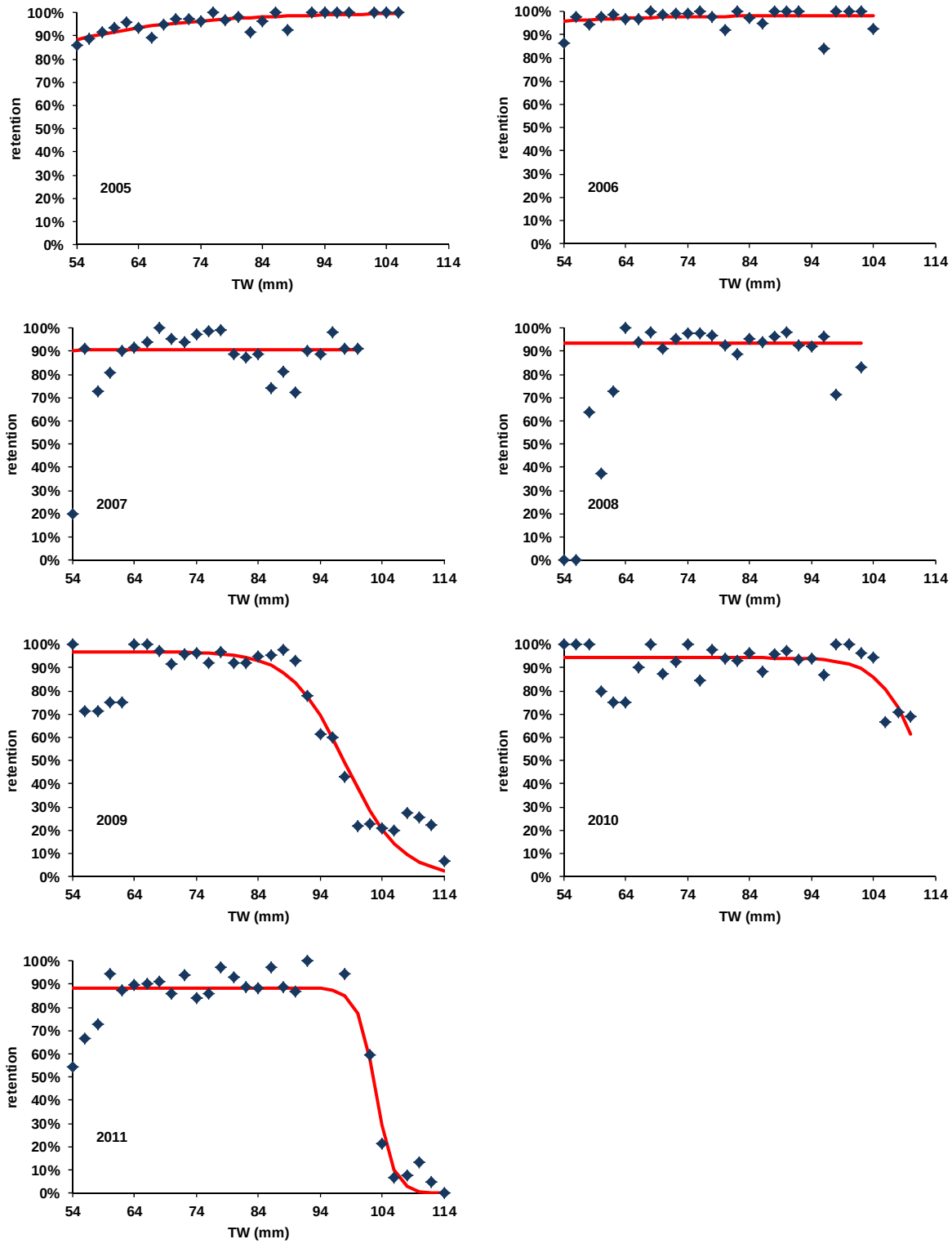

Figure B1: CRA 9 males: Percentage retention versus size by year, using only size bins with at least 10 fish caught; red lines are fitted curves; red lines are the fitted curves.

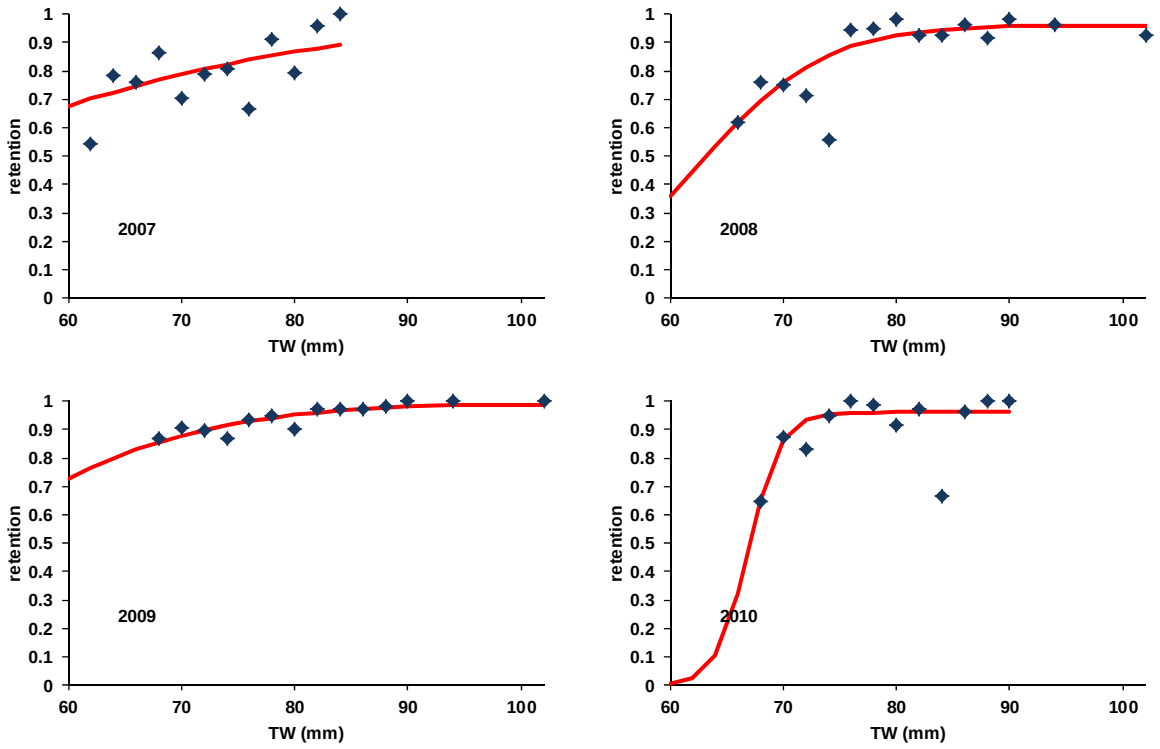

Figure B2: CRA 9 females: Percentage retention versus size by year, using only size bins with at least 10 fish caught; red lines are the fitted curves.

Retention by weight

The data in figures above were converted to weight using the length-weight relations described by Nokome Bentley (unpublished data, see Table 5). The total weights of males and females were calculated and summed, and also weights of fish retained, then the percent discarded was calculated from the difference.

Retention has decreased markedly in the past three years, and in the most recent year of data nearly half the legal fish (by weight) were returned to the sea (Table B8).

Table B8: CRA 9: Estimated weight of legal fish returned to the sea by sex and year.

		Male	Female	Total	Discarded
2005	caught	1 382.7	62.8	1 445.5	3.6%
	retained	1 334.6	58.8	1 393.3	
2006	caught	1 628.3	69.3	1 697.6	4.5%
	retained	1 560.6	60.4	1 621.0	
2007	caught	2 666.9	335.6	3 002.6	11.3%
	retained	2 389.7	274.4	2 664.1	
2008	caught	2 065.1	1 455.0	3 520.1	6.6%
	retained	1 928.4	1 360.3	3 288.6	
2009	caught	3 024.8	1 443.1	4 467.9	28.6%
	retained	1 804.3	1 386.0	3 190.3	
2010	caught	1 717.9	3.0	1 720.9	12.6%
	retained	1 500.7	3.0	1 503.7	
2011	caught	1 812.2	399.2	2 211.4	47.5%
	retained	789.1	372.8	1 161.9	

Data from the CRA 9 logbook program appear to be good. The percentage of fishers reporting is high, but the fleet is small, so numbers of fishers reporting are small. Very few records had to be removed because of missing data; reported retention of non-legal fish was low; no non-recording of retention occurred from 2005 onwards and no fisher reported 100% retention consistently.

For males, retention decreased over time. Curves were flat until 90 mm TW and then curves declined above 90 mm in the three most recent years. This contrasts with CRA 8, where retention for males declined steeply after 70 mm TW (Starr et al. 2013). Retention of females was lower at smaller sizes, but showed no pattern over time.

Retention by weight showed a strong decreasing trend, with almost half the weight caught returned to the sea in 2011.

APPENDIX C: CRA 9 TAG-RECAPTURE DATA

These data were presented to the RLFAWG as part of the CRA 9 characterisation in June 2013. Growth was estimated from them (see Table 4) as part of determining a prior distribution for the intrinsic rate of increase.

Data were extracted in September 2012 by Paul Starr and processed with the purpose-built software developed by Nokome Bentley (unpublished). This software:

- matches recaptures to releases, treating re-recaptures as having been released at the previous recapture
- calculates tail width from carapace length where necessary, using relations developed in the Breen et al. (1988) morphometrics program [not necessary for the CRA 9 tags]
- discards records with missing tail widths at release or recapture
- discards records with inappropriate sex codes or apparent sex changes
- discards records with apparent shrinkage greater than 10 mm
- discards records with an increment greater than 40 mm.

Data contained information on sex; sizes, dates and areas of release and recapture; tag type and condition.

After the grooming just described, the extract contained 61 records. Four records were from short times at liberty (less than 30 days) and were removed. Of the 57 remaining records, 26 were males and 31 were females. Sizes at release by sex are shown in Table C1. Males were mostly below MLS; females came from a good range of sizes.

Table C1: CRA 9: Numbers of recaptured tags that were released in each 5-mm TW size bin.

Bin	Males	Females
45	1	
50	15	1
55	3	7
65	4	6
70	2	4
75	1	4
80		6
85		3
Total	26	31

Releases were made from October 1999 through December 2003; recaptures from December 1999 through December 2009. Times at large ranged from 72 to 2177 days (6 years), with median 309 days (see Figure C1).

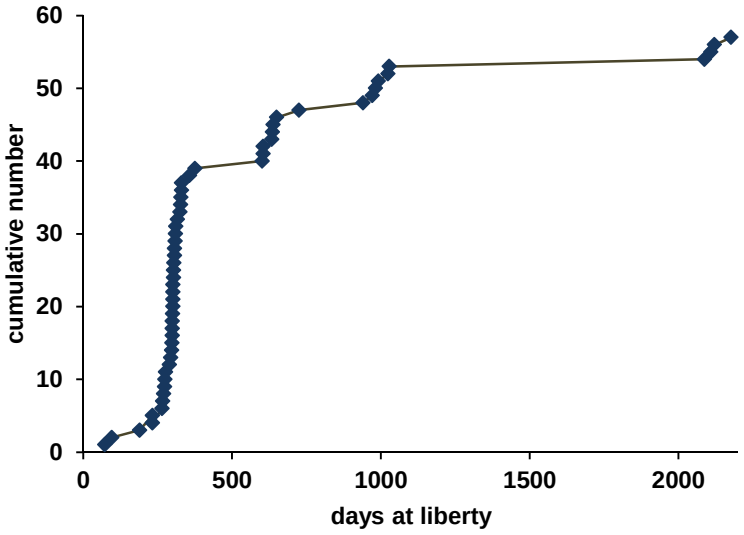

Figure C1: CRA 9: Cumulative distribution of times at liberty for tags recaptured.

Most recaptures were tagged in area 935 (Manawatu to Oakura), and were recaptured in the area of release (Table C2).

Table C2: CRA 9: Areas of release and recapture of tagged fish.

	Recaptured		
Released	931	935	936
931	9		
935		43	
936			5

All but two fish were recaptured only once, and the two were recaptured only twice. Condition codes were mostly zero, with one missing and three "1" (this indicates a leg or an antenna missing). Tag type was all "4" for Hallprint T-bar tags.

Apparent increment ranged from -6 to 21 mm TW. Increments were "annualised" based on days at large:

$$I_i^{ann} = \frac{365\left(l_i^{rec} - l_i^{rel}\right)}{d_i} \quad (26)$$

where I_i^{ann} is annualised increment for the *i*th record, l_i^{rel} and l_i^{rec} are the sizes at release and recapture and d_i is the number of days at liberty. The scale of these increments was from minus 25 to 12 mm TW. These are shown for males and females in Figure B2. The annualised increments are a convenient way to look at the data; growth is not estimated from them but from the raw data, including time at liberty.

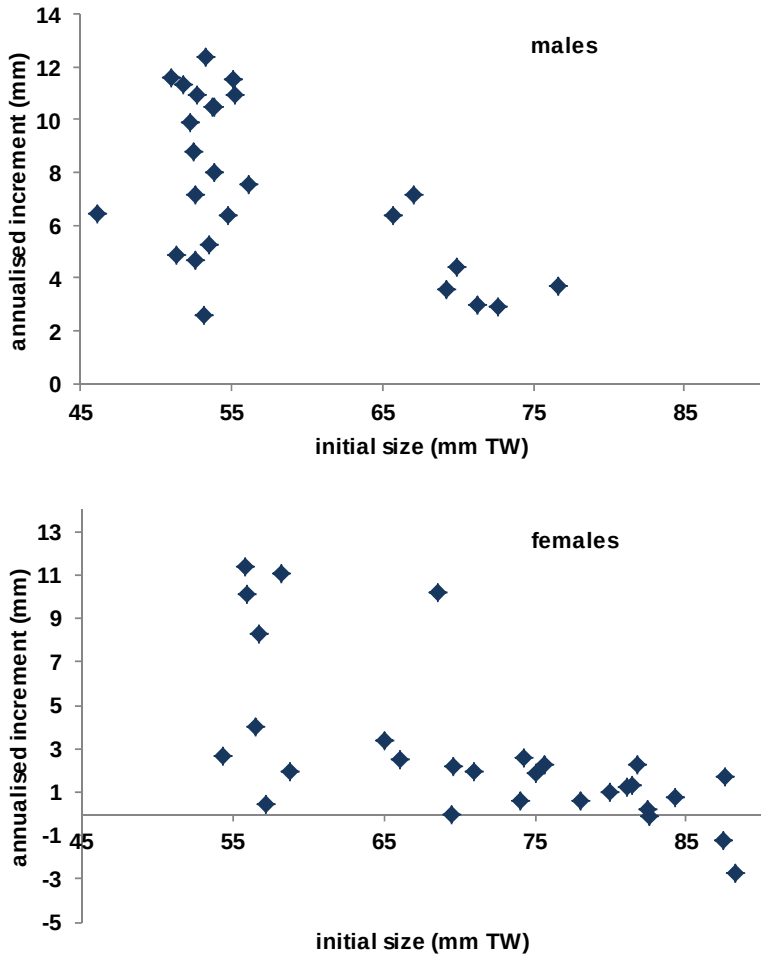

Figure C2: CRA 9: Annualised increments as a function of initial size; for females, two large negative increments of minus 23 and minus 25 mm are not shown

APPENDIX D: RECREATION CATCH ERROR

Recreational catch was estimated for CRA 9 based on the large-scale multi-species survey (LSMS) contracted by MPI to the National Research Bureau (unpublished results). As described above, the estimation assumed that recreational catch is proportional to spring-summer (SS) CPUE, and was keyed to the LSMS estimate for 2011. Recreational catch is an important component of the total catch used by the model, and determines the recreational catch in projections.

In early October, after the evaluations had been reported to the RLFAWG in September, an error was discovered by MPI in the CRA 9 LSMS estimate. Neville Smith, the Chair of the Marine Amateur Fisheries WG, sent the stock assessment team, via Kevin Sullivan, revised values for the CRA 5 and CRA 9 recreational catch estimates. See the email below.

This change came about through an NRB coding error that assigned some CRA 5 catch to CRA 9. When this was discovered, the effect was to change the estimates for the period 1 October 2011–30 September 2012 as follows:

QMA	Old numbers	Old weight (t)	New numbers	New weight (t)
CRA 5	43 000	36.22	49 300	43.47
CRA 9	21 800	25.21	15 500	17.96

Kevin Sullivan reasoned that this change was small and did not warrant any modification of the current CRA 9 MPE (see his email below).

Paul Starr compared the CRA 9 recreational catch vectors from the original LSMS estimate (25.2 t for 2011) and from the corrected estimate (18 t), using a revised CPUE extract obtained in September. The comparison is shown in Table D1 and Figure D1: the only difference is in the 2012–13 fishing year, where SS CPUE dropped by 7.3% from 3.02 to 2.80 kg/potlift. Figure D2 compares the original and revised recreational catch vectors (showing a 26% decrease), and shows the high and low sensitivity trials: the revised vector lies between the original base case and the low catch sensitivity trial. Any change in the LSMA estimate is reflected directly in the recreational catch vector because there are no other survey estimates for CRA 9. However, the effect on the total catch vector is negligible: total catch drops by only 2.3% (Figure D3).

Table D1: Comparison of recreational catch vectors made with three combinations of LSMS estimate and CPUE extract.

SS CPUE series used	Scaled to:	Sum of recreational catch (1945–2012)	Total 1945–2012 catch (commercial, recreational, illegal, and customary)
Apr 2013 extract	25.21 t	1 002 t	11 486 t
Sep 2013 extract	25.21 t	973 t (-3%)	11 457 t (-0.3%)
Sep 2013 extract	17.96 t	738 t (-26%)	11 222 t (-2.3%)

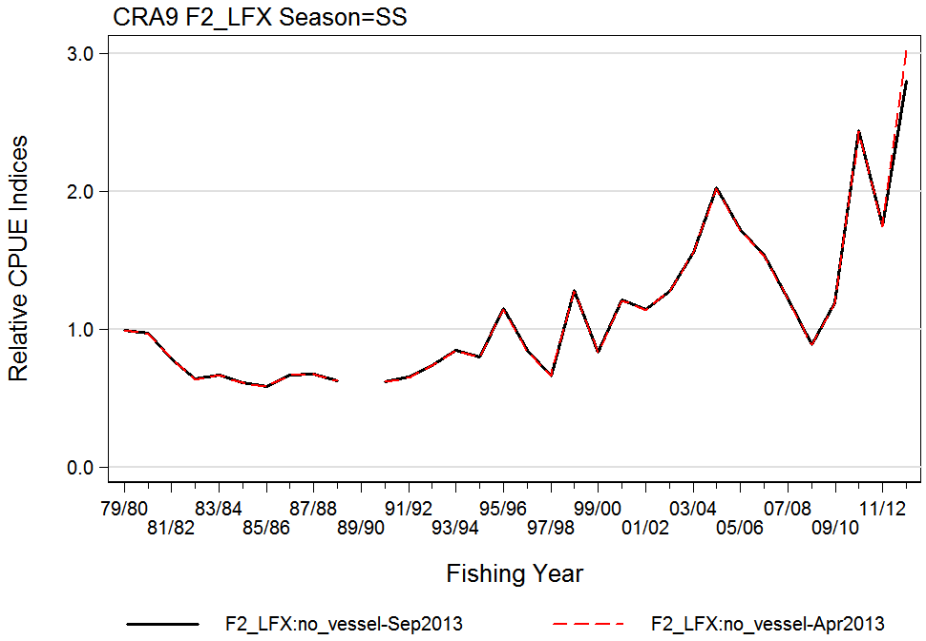

Figure D1: Comparing the spring-summer CPUE trajectories for CRA 9 calculated from the April 2013 data extract for the CRA 9 MPE and from the September 2013 extract.

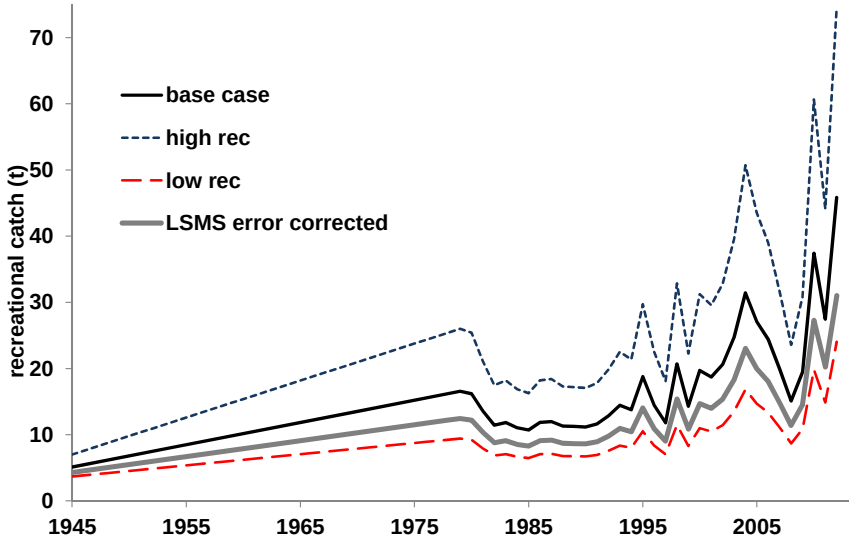

Figure D2: Plot comparing the CRA 9 recreational catch vector after correcting the LSMS error (grey) with the base case and the high and low sensitivity trials.

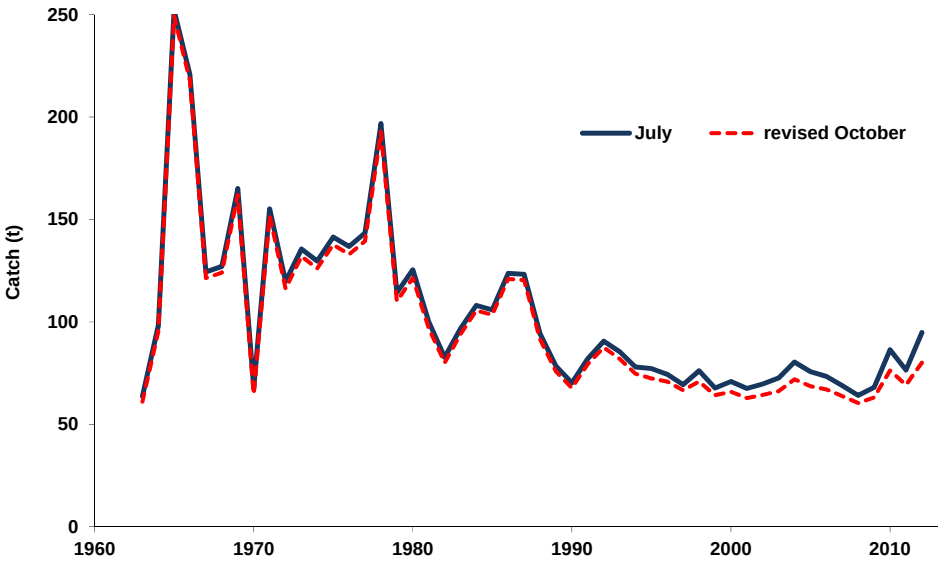

Figure D3: CRA 9 total catch vector estimated in July, using the LSMS estimate provided then, and in October after correction of the error.

Email from Dr. Kevin Sullivan, 4 October 2013 (typos in attached material corrected)

Date: Fri, 04 Oct 2013 01:51:20 +0000
From: Kevin Sullivan <Kevin.Sullivan@mpi.govt.nz>
Subject: FW: CRA and national panel survey

Paul et al.,

Today we received the following update from Neville. On Wednesday at the NRLMG he mentioned a coding problem with the scallop and paua estimates (caused by alpha-numeric codes for some areas), but unfortunately CRA also had coding errors where catch of 7.25 t in area 40C was coded to CRA 9 instead of to CRA 5. Thus the estimate in CRA 9 now goes down 7.25 t. I will send the map of the areas in a following email [See Figure D4].

In terms of the production model I do not think it makes any difference, and there is no point in changing that model. In terms of the MP I think it is relatively minor; however, the CPUE jump in 2012 increased the estimate of recreational catch to 45.83 t. This now appears to be too high, the comparable figure would be more like 32 t.

From my perspective the MP results are still valid and the rules will operate as designed. The results from a rerun would probably look something half way between the base and robustness test R3.

Kevin

[attached]
From: Neville Smith
Sent: Friday, 4 October 2013 11:37 a.m.
To: Alicia McKinnon; Kevin Sullivan
Subject: RE: CRA and national panel survey

Hi

The revised numbers below
Crayfish/Lobster Spiny/Red

QMA.CRA	Number of events	Number of fishers	Number of fish	CV	Weights (t)	CV	Mean weight (kg)
5	143	44	49274	0.23	43.47	0.24	0.88
9	58	22	15534	0.3	17.96	0.3	1.16

I also asked Alistair to tabulate the event/fisher numbers by the 52 smaller areas. This allows one to look at where catch was reported from (one of the repeated lines of questioning at the NRLMG).

Neville

QMA CRA	Area	Number of events	Number of fishers
1	1	12	7
1	2	11	8
1	3a	39	14
1	3b	0	0
1	4	19	7
1	5a	0	0
1	24	0	0
1	25	9	1
2	5b	44	17
2	6	17	9
2	7	9	7
2	8	4	3
2	9	4	4
2	10	40	24
2	11a	13	4
2	11b	0	0
2	12	4	3
2	13	32	8
2	14a	1	1
3	14b	34	18
3	15a	13	8
4	15b	84	29
4	16	44	20
4	17	59	19
4	18b	19	5
5	26	3	2
5	27	9	5
5	28a	1	1
5	28b	6	3
5	29	82	24
5	30	11	6
5	31	15	4
5	32	0	0
5	40c	16	4
7	33	1	1
7	34a	0	0

QMA CRA	Area	Number of events	Number of fishers
8	34b	0	0
8	35	0	0
8	36	0	0
8	37	0	0
8	38	12	3
8	39b	7	4
9	18a	2	2
9	19	27	10
9	20	7	4
9	21	2	2
9	22	0	0
9	23	1	1
9	39a	18	4
9	40a	0	0
9	40b	1	1

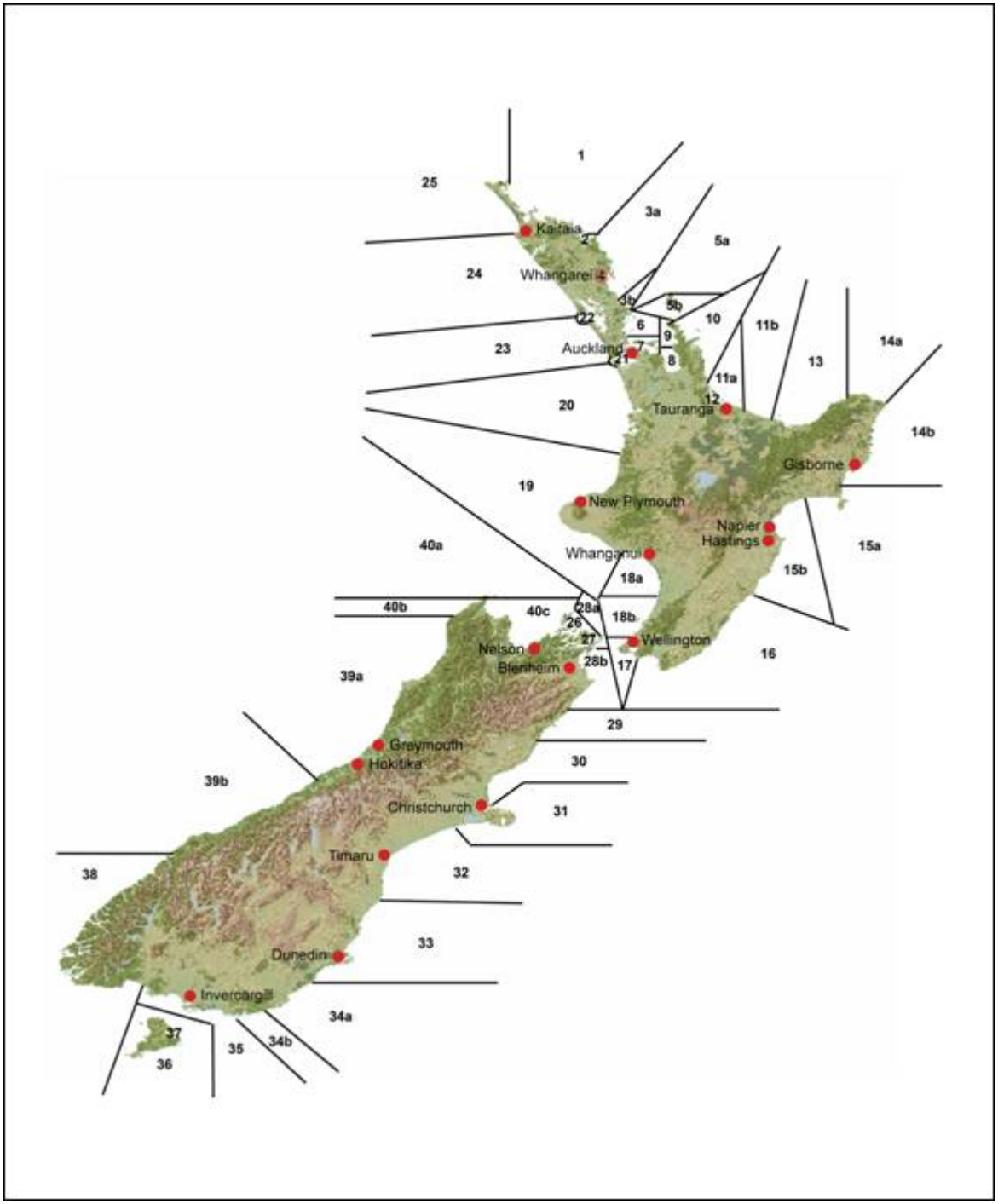

Figure D4: LSMS areas mentioned in the email above; area 40c was assigned to CRA 9 instead of CRA 5 in the original LSMS estimates.