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CRA 6 management procedure evaluations

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EXECUTIVE SUMMARY

Breen, P.A. (2009). CRA 6 management procedure evaluations.

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This report describes work towards development of a management procedure for CRA 6. Data from CRA 6 are presented and discussed: length frequencies, catch and CPUE data from the beginning of the fishery. Catch and CPUE data are used to estimate annual production using simple assumptions.

Next, two simple assessments are described that involved fitting simple production models to the data. These were a constant production and a surplus production model. Both were implemented in AD Model Builder, and posterior distributions of estimated parameters were obtained from Markov chain – Monte Carlo simulations.

Both models were programmed as operating models, with stochastic variation in annual production based on the patterns observed in the data. A family of harvest control rules was defined, a standard set of indicators was defined, and simple explorations were made of the productivity characteristics of the models. Then more focused explorations were made, and finally a narrowed set of 60 rules was evaluated.

The next step in this project will be to discuss the results with the CRA 6 industry and determine what they want to obtain from a management procedure and what they expect from the major trades-off seen among rules. From these discussions and the extant results, final rule candidates will be chosen and evaluated.

1. INTRODUCTION

Although rock lobsters (*Jasus edwardsii*) were known from early surveys (Waite 1909) to be abundant at the Chatham Islands, the commercial fishery began seriously there only in the 1960s; it expanded rapidly in a "boom" (Anon. 1966, 1969; Kensler 1969, Arbuckle 1971, Waugh 1973). Catches peaked in 1968 at 6000 tons, then fell rapidly over the next seven years to near 350 t, and have remained in the 300–600 t range since then, averaging 393 t since 1975. A similar sharp decrease was also seen in CPUE, from nearly 1 t/vessel-day to less than 100 kg. The full data will be presented and discussed below.

This fishery was brought into the Quota Management System in 1990 and the management area is called CRA 6. This is a large area, comprising waters within 200 nautical miles of the Chatham Islands and Bounty Islands, but fishing is confined to a narrow region next to the Chatham Islands coastline. The initial TACC was 530 t after appeals, but was reduced to 400 t in 1997 and to 360 t in 1998 because of concerns about declining stock. In 1998, the TAC made allowance for 4 t customary and 6 t recreational catch.

Unlike lobster fisheries elsewhere in New Zealand, the CRA 6 fishery has a dive component, in which some participants may legally take lobsters commercially with scuba. However, the catch per unit effort data from this method have never been worked up.

A simple assessment was done by Breen & Kendrick (1998), suggesting an annual stock productivity of about 350 t. There has been no subsequent assessment, and the TACC has remained at 360 t. A research programme was initiated in 1995 (NIWA unpublished data) but local interest was limited and this did not continue past 1997.

The study reported here addressed the possibility of a management procedure for CRA 6. Management procedures are extensively simulated-tested decision rules: see Johnston & Butterworth (2005) for discussion of a management procedure used to manage rock lobster in South Africa. They have been used to rebuild the depleted CRA 7 and CRA 8 stocks in New Zealand (Breen et al. 2009). A management procedure was used to govern voluntary ACE shelving in CRA 4, to attempt to rebuild a badly depleted stock, and has now been adopted by the Minister of Fisheries as a TACC-adjusting rule (Breen et al. 2009). A management procedure has been adopted by CRA 5 as a voluntary ACE-shelving rule to maintain high abundance (Breen 2009).

This study uses an operating model that is similar to the assessment approach of Breen & Kendrick (1998). Productivity of the stock is first explored using a variation of the method described by Hilborn (2001) (see also Walters et al. 2008). Next, simple stock assessments are performed with two simple models: a constant-production model and a surplus-production model. A family of harvest control rules is defined. Forward projections are made with different harvest control rules, and a set of fishery indicators is defined for use in evaluating rules.

Preliminary explorations are made to scope out the productivity characteristics of the stock under the two operating models. Then a series of evaluations is described to identify suitable harvest control rules that could be used in a CRA 6 management procedure.

2. CRA 6 DATA

2.1 Size frequency data

This study relied heavily on CRA 6 catch and effort data, but there are also some historical size data, and recent data from a voluntary logbook programme that began in 2001(NZ RLIC, unpublished data). The numbers of fish measured in the logbook programme from 2001 to 2008 are shown in Table 1. The resulting size frequency distributions, based on tail width, are shown in Figure 1 and Figure 2.

Few fish were measured in 2001. The frequencies have spikes on 60 and 70 mm, etc., indicating that the scale of measurement in at least some logbooks is coarse: some fishers are measuring to the nearest 10 mm. With a narrower range of sizes measured this would be a serious problem, but the range of sizes measured is large in CRA 6. There is an abundance of fish well above the MLS.

Cumulative proportions are shown in Figure 3. Even when 2001 is ignored, there is a trend for the earlier years to have larger sizes than the later years, but the pattern is stable for the last four years. The median size by sex for each year is shown in Table 1. These are quite large compared with other New Zealand fisheries.

Sizes of CRA 6 lobsters are puzzling. Based on early catch sampling, the size frequencies did not change much between 1966 and 1994, although medians did appear smaller in 1982 (Breen & Kendrick 1998) based on unpublished data from R. Coombs, J.D. Booth and the Ministry of Fisheries (see also Kensler 1969). Yet, as shown below, changes in CPUE suggest that the stock decreased substantially from 1963 to 1994. In a stock that has been fished down, one expects to see a reduction in average size, but that was not the case in CRA 6 until 1994.

Results of 1995–97 catch sampling (Breen & Kendrick unpublished 1997) are seen in Figure 4 to Figure 7. In general, these samples show medians that are consistent with those seen in the early years of Table 1. Note the differences among statistical areas (these no doubt contribute to the year-to-year variability of catch samples in the earlier data), and note the strong suggestion of bimodality in Figure 5. In all figures there is an abundance of fish well above the MLS: similar patterns were seen in market sampling.

Thus, sizes did not change markedly from 1963 to 1997 although the stock was heavily fished down. Sizes did decrease somewhat between 1995 and 2008, when (as will be shown below) exploitation rate actually decreased. It is possible that the recent decrease in median size was caused by increased recruitment to the stock. Juveniles can be found at the Chatham Islands (Banks & Anderson 1997), but their distribution is not general, and in size frequencies their relative abundance is low.

2.2 Catch data

CRA 6 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 2 and Figure 8. The version of catches used in this study is that contained in the CRACE database (Bentley et al. 2005).

Commercial landings reflect the "crayfish boom" at the Chatham Islands between 1965 and the mid 1970s (Kensler 1969, Arbuckle 1971, Waugh 1973). Commercial landings increased from 15 t in 1965 to 6300 t in 1968, but declined to 340 t in 1975. They have fluctuated between 300 and 600 t since then.

Non-commercial catches are very poorly known. The allowance made in the TAC is 10 t. This study assumes the 10 t allowance for non-commercial catch (recreational, customary and illegal) for the whole period; this may be an over-estimate for the early years.

2.3 CPUE data

Catch per unit of effort is estimated in arithmetic kg/day for 1965 to 1992, and in standardised kg per pot lift for 1979 to 2008 (P.J. Starr, pers. comm.). The estimates for catch per day were made by Kendrick (unpublished data) based on data from Annala & King (1983) for 1965 to 1973, from Annala & Esterman (1986) for 1974 to 1978, from annual FSU reports by Brian Sanders for 1979 to 1986, from Booth et al. (1994) based on FSU data for 1987 to 1989 and QMR data for 1990 to 1992. In this study, catch per day was used only for 1966 to 1978.

Estimates of CPUE in catch per pot lift were provided by Paul Starr (unpublished data). They are standardised estimates, after grooming, as described by Bentley et al. (2005).

CPUE estimates are shown in Table 2 and in Figure 9. CPUE showed a steep decline from its peak in 1967 and 1968 over the next two years. Catch per potlift showed a slow decline from over 2 kg/potlift 1979 to a low of just over 1 kg in 1994, followed by a slow increase to the current level of 1.6 kg/potlift.

3. OBSERVED PRODUCTION

The data in Table 2 can be used to estimate production if catchability is assumed. Biomass can be estimated as

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

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

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

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 2009).

Using estimates of catchability from the constant production model described below, 4.002×10^{-5} for catch per day and 7.519×10^{-7} for kg/pot, biomass and production estimates are shown in Figure 10 and Figure 11.

Production is shown plotted against biomass in Figure 13. Because of the small CPUE for 1965, estimated production was very large for that year; most of the contrast is in the next four years. Figure 14 shows the relation with the first five years eliminated: there is little relation between production and biomass.

Exploitation rate (observed catch divided by estimated biomass) is shown in Figure 15.

Another (but not independent) way of looking at the data is shown in Figure 16. The CPUE has been plotted against accumulated catch minus a constant production of 388.7 t (kg/day was converted to kg/potlift by using the average pots/day 1979–82: this was of 52.2. For years after 1967, the data lie comfortably on a straight line, suggesting that annual production has been roughly constant.

4. OPERATING MODELS

4.1 A surplus-production model

I fitted a simple surplus-production (SP) model to these data. The model predicts production as a function of biomass:

(3) $$P_t = \frac{r}{p} B_t \left(1 - \left(\frac{B_t}{B0}\right)^p\right)_t$$

where *r*, *p* and *B0* (=*K*) are parameters of the model. *Bmsy* is given by

(4) $$Bmsy = B0\left(\frac{1}{1+p}\right)^{\frac{1}{p}}$$

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

The model was fitted by using an "observation error time series" approach (see Hilborn & Walters 1992). The 1965 biomass was made equal to *B0*, and subsequent biomass was determined by this rearrangement of (2):

(5) $$B_{t+1} = B_t + P_t - C_t$$

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

(6a) $\hat{I}_{t,day} = q_{day} B_t$ for catch per day, 1966 to 1978

(6b) $\hat{I}_{t,pot} = q_{pot} B_t$ for catch per pot, 1979 to 2008

Predicted and observed CPUE values were compared with robust log-normal likelihood (Bull et al. 2008):

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

where σ_{day} is an estimated parameter. The likelihood for catch per pot is analogous. Normalised residuals are:

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

The model was implemented both in Excel™ and AD ModelBuilder™. Weights were programmed, so that the relative weight applied to the catch per day and catch per pot data could be varied, but they were left at 1 for both data sets.

Each of the seven estimated parameters was given a uniform prior with wide bounds (Table 3). In exploratory runs, it was not possible to obtain a positive definite Hessian matrix without *p* on its lower bound; to avoid this, *p* was fixed to 0.3.

The fits between observed and predicted CPUE from the mode of the joint posterior distribution (MPD) (in this case, the same as a purely maximum likelihood fit) are shown in Figure 17 and Figure 18. The fit to kg/day was good (the first observation was not used in fitting), and the fit to kg/pot was good except for the first three values, 1979–81. The catchability for kg/day was 71.6 times that for kg/pot: this compares with 61 pots per day in the data for 1979–84 (T. Kendrick, unpublished data) .

“Observed” (from the simple procedure described above) and predicted production as functions of biomass are compared in Figure 19 and Figure 20 – remember that the model is not fitting to production. Most of observed production is at the low end of the biomass range, suggesting that the estimated surplus production function should be treated with caution.

Uncertainty in the parameter estimates was estimated using Markov chain – Monte Carlo simulations (McMC). An McMC was first run with 5 million simulations, saving 2000 samples. Because the diagnostics of this run were not good – the runs showed poorly mixed traces and a marked trend through the run – a longer chain of 200 million simulations was made. Diagnostic plots for the parameters are shown Figure 21 (traces) and Figure 22 (running quantiles and moving mean). For *R0*, *r* and the two catchabilities, there was an excursion towards high *B0* and low *r* just past the middle of the chain, after 100 million simulations. This is not the best of behaviours for an McMC chain, but the chain is adequate for use in the operating model.

The median standardised residual of normalised residuals for CPUE in kg/pot was higher than 1 (Table 4), but the weights were left at their natural values.

The posterior distributions of estimated and derived parameters are summarised in Table 4. Estimated parameters had reasonably narrow distributions despite the excursions. Biomass indicators were somewhat more variable. Current biomass was estimated at nearly twice *Bmin*, and at 11–16% of *B0* (5% to 95% range). The median of current biomass as a percentage of *Bmsy* was 32%, with a range from 27 to 38%.

According to this model, current biomass is well below *Bmsy* and *MSY* is much higher than the current catch level, with a total catch between 650 and 800 tonnes, whereas current production is from 415 to 486 tonnes.

4.2 A constant-production model

An alternative model was fitted. In this model, predicted production was an estimated constant instead of being a function of biomass. All other aspects were the same as described above for the SP model. This constant production (CP) model had only six parameters, with bounds as shown in Table 3 for the common parameters, and bounds on the constant production of 10 thousand to 1 million. Biomass change is described by equation (5), where *P* is an estimated constant. Likelihoods and fitting were the same as for the SP model.

The fits to CPUE are shown in Figure 23 and Figure 24; both were reasonable. The ratio of the two catchability estimates suggested 53.2 pots per day. The estimated constant production of 376 t is compared with observed production in Figure 25.

The fit was marginally better at 51.3 likelihood units than the fit from the surplus production model (52.7). Both models had six estimated parameters.

An McMC was run with 5 million simulations, saving 2000 samples. Diagnostic plots for the parameters are shown in Figure 26 (traces) and Figure 27 (running quantiles and moving mean). These diagnostics are much better than those for the SP model, and they suggest that the short chain, if 5 million simulations is short, was adequate.

The posterior distributions for the estimated and derived parameters are shown in Table 5. Estimated parameters had narrow distributions, and *constantP* varied only from 368 to 384 t. Current biomass was 34–55% above *Bmin*, and was 9–12.5% of *B0*. There is no estimate of *Bmsy* because the model has constant production at all biomass levels.

The medians of normalised residuals for CPUE were both close to 1 (Table 5).

4.3 Discussion of operating models

The two operating models fit the data almost equally well. Certainly both models fit the CPUE data credibly, with some poor fits only in the first three years of catch per pot data for the SP model. For both models there is a good correspondence between predicted and observed production (see Figure 19 and Figure 25), but there is very little contrast in biomass over the period modelled (see Figure 10 and Figure 20).

It is the lack of contrast in biomass that allows the similar fit for the two models. This fishery is an extreme example of the "one-way trip" described by Hilborn & Walters (1992). Because biomass has only a narrow range after the first few years of the fishery, production predicted by the SP model also has a narrow range, and is not very different from the predicted constant production (mean 416 t from 1979 to 2008 from the SP model, compared with 385 t constant production).

Neither model is fully credible. The assumption of constant production depends on external input to the CRA 6 fishery: that is the only mechanism that would allow constant production from a low stock size. This is consistent with the large lobsters seen in the fishery, discussed above, but remains a speculative mechanism. Some observers have speculated that migration supports the fishery (Stevens 1996).

The SP model suggests that more than twice the current yield could be taken if the stock were rebuilt to *Bmsy*. However, the size distribution of the catch may be incompatible with a stock reduced to 30% of

Bmsy and fished at a current exploitation rate of 21% (the mean rate from the SP model MPD over 1979 to 2008). And in any case, Figure 20 suggests that *Bmsy* must be poorly determined because of the lack of contrast in biomass.

Implications of the two models are different. The SP model implies that a catch of roughly double the current TACC of 360 t could be taken by allowing the stock to double. The CP model implies that the long-term catch could be only slightly greater than the current catch, and that this could be taken from a wide range of stock sizes.

5. HARVEST CONTROL RULES

Two harvest control rule families were used in this study. The first was used only for exploratory runs, and the second was used in actual evaluations.

Rule 1 has a constant TACC, which can be zero.

Rule 4 is a new, flexible form that includes the existing rules for CRA 4, CRA 5, CRA 7 and CRA 8. In its most basic form, the TACC is a simple function of observed CPUE in the previous year (Figure 28). In this simplest form, the rule can of course have many slopes, and so even the simplest form describes a whole rule family.

The rule can be modified in several ways. First, a shape parameter can deliver a rule that is curved (Figure 29). In this figure, TACC declines more quickly than CPUE when CPUE is below 2, and it increases more quickly than CPUE when CPUE is above 2.

Second, the rule need not go through the origin: a "shutdown threshold" for CPUE can be specified, below which the TACC is zero (Figure 30). A higher threshold, "left plateau threshold", can be added, above which TACC does not increase, creating a plateau (Figure 31), and this can have an upper threshold or "right plateau threshold", above which TACC increases again.

This rule is parameterised as follows. The lower slope is determined by two parameters that can be thought of as "target CPUE" and "target catch limit". In practice, these are just parameters, and a rule will not necessarily deliver either the target CPUE or the target catch as long-term means. The rule makes the catch limit equal to "target catch limit" when input CPUE is equal to "target CPUE". Other parameters are as follows.

par1 rule type
par2 "target catch"
par3 "target CPUE"
par4 shape parameter
par5 first CPUE threshold (shutdown threshold)
par6 second CPUE threshold (plateau left)
par7 third CPUE threshold (plateau right)
par8 upper slope
par9 minimum change threshold
par10 maximum change threshold
par11 latent year switch

Ignoring the minimum and maximum change thresholds, the harvest control rule is defined as follows. T is catch limit and I is input CPUE; year subscripts are omitted for simplicity.

(9) $T = 0$ for $I < par5$

(10) $T = par2\left(\frac{I - par5}{par3 - par5}\right)^{par4}$ for $par5 \le I < par6$

(11) $T = par2\left(\frac{par6 - par5}{par3 - par5}\right)^{par4}$ for $par6 \le I < par7$

(12) $T = par2\left(\frac{par6 - par5}{par3 - par5}\right)^{par4} + par8\left(I - par7\right)$ for $I \ge par7$

Equation (9) gives a catch limit of zero when CPUE is below the shutdown threshold. Equation (10) gives the catch limit up to the start of a plateau, if present; (11) describes the catch limit on the plateau and (12) describes the increasing catch limit above the plateau right threshold, if present.

Normally, $par5 < par3 \le par6 \le par7$. The rule may function with other arrangements, but then the catch limit may differ from *par2* at CPUE = *par3*.

The minimum change parameter prevents a change to the TACC when that change would be less than the parameter. The maximum change parameter prevents a change to the TACC when that change would be greater than the parameter.

An *ad hoc* modification was made to the maximum change procedure; this was necessary because the constant production operating model allows the stock to reach very low levels with correspondingly low TACCs and, with maximum change of 50%, a decade may be required for the TACC to increase to an appropriate level. Under the modification: when the maximum change limit is invoked, if the TACC after applying the maximum change limit is less than half the TACC suggested by the rule, the TACC is made equal to half the TACC suggested by the rule.

The effect of this modification is illustrated from test runs in Figure 32. The unmodified procedure had a TACC lagging well behind a strong recovery of the stock; the modified procedure tracked the stock more closely. In model testing, the modification was invoked only at very low stock sizes, and this was in only 0.2% of years (of course, this frequency will depend on the rule being tested).

The latent year switch has three options: 0 (no latent year) allows TACC changes every year; 1 (latent year) allows TACC change only when no change was made in the previous year; 2: (asymmetric latent year) allows a TACC decrease in any year, but allows an increase only when no change was made in the previous year.

6. PROJECTIONS

Projections were made by running the dynamics forward (equation (5)). The current TACC of 360 t was used for 2009; in subsequent years the annual TACC was determined by the harvest control rule being tested. CPUE used as input to the model was determined from model biomass and the model's catchability of kg/potlift. To this was added lognormally distributed observation error:

(13) $$\hat{I}_t = q_{t,pot} B_t \left(\exp(\xi_t \sigma_I) - 0.5\sigma_I^{\,2} \right)$$

where σ_I is the standard deviation and ξ_t are random normal deviates with mean zero, standard deviation 1. The standard deviation was set to 0.15 after experimentation (Figure 33).

Dynamics incorporated production deviations. In the pre-projection years, these were calculated as

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

where $\hat{P}_t$ is production estimated by the surplus production of constant production model and P_t is estimated by equation (2). Both trajectories show a large change in the scale of these deviations in the late 1970s or early 1980s. The standard deviations are much smaller (but still considerable) for 1979–2007 than for 1966–2007 (Table 6).

When the whole series was used in exploratory projections, the rate of collapsed runs in the constant production model was 5% with no fishing, and the scale of biomass fluctuation was far higher than that seen in Figure 10 after 1979. Accordingly, the base case projections resampled deviations from 1979 to 2007. Because negative deviations were often larger than biomass, biomass was arbitrarily truncated at 1 t. When TACC exceeded 75% of biomass, the catch was truncated to 75% of biomass (i.e., exploitation rate was truncated at 75%).

Runs were made through 2060, and indicators were sampled for the 50 years 2010 through 2059. For each set of runs for a harvest control rule, projections were made from each of the 2000 samples from the joint posterior, obtained from the McMC simulations.

7. INDICATORS

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

- nLTBmin: the number of years, 2010–2059, in which biomass was less than *Bmin*
- nLT15: the number of years in that period in which CPUE (with error) was less than 0.15 kg/pot
- collapse: 1 if at any stage during a run the biomass became less than 1 t, otherwise zero
- minTACC: the minimum TACC from 2010 to 2059
- meanCatch: mean of total catch from that period
- minCatch: the minimum of total catch in that period
- CPUEproj: CPUE in 2059, observed with error
- minCPUE: minimum of CPUE from 2010 to 2059
- meanCPUE: mean of CPUE in that period
- Bproj: biomass in 2059

- AAV: the average annual change in TACC

and additional indicators were defined for the surplus production model:

- nLTBmsy: the number of years in which biomass was less than Bmsy
- Bproj/Bmsy: biomass in 2059 as a proportion of Bmsy
- meanCatch/MSY: mean catch as a proportion of MSY

Indicators were written from each run, and were summarised for a set of 2000 runs by the mean of the posterior distribution except for collapse, which was 0 or 1 for each run, and so was summed for a set of runs. For nLTBmin and nLT15 the rates (percentage per year) were sometimes calculated, and the collapse indicator was sometimes summarised as the percentage of runs that collapsed.

8. PRELIMINARY EXPLORATIONS

For both the SP and CP operating models, sets of runs were made with two families of rules: rule 1 with various constant TACCs from zero to 800 t, and a simple Rule 4 with various "target catches" from zero to 800. For rule 4, the shape was set to be linear, the rule went through the origin and there was no plateau; min was set a small value and max was set to a large value; there was no latent year. Thus the form of the rule was as shown in Figure 28.

The multipliers used in Rule 4 determine the TACC at CPUE = 1 kg/potlift.

Summaries are shown in Table 7 (surplus production, constant catch), Table 8 (surplus production, Rule 4), Table 9 (constant production, constant catch) and Table 10 (constant production, Rule 4).

Some indicators are plotted against the rule inputs in Figure 35, and two indicators are plotted against the mean catch indicator in Figure 36. A typical but non-randomly chosen run (430) is compared in Figure 37.

For a given level of constant catch, the SP model was more likely to show collapse than the CP model. However, the SP model showed much higher mean biomass (as reflected by meanCPUE), and thus lower values for the abundance indicator nLT15. Mean catch was slightly higher for the CP model at the TACCs where mean catch was less than the TACC, and was much higher at the highest TACCs.

The current TACC of 360 t, as a constant level, is acceptable under both models except for the likelihood of collapse (approaching 5% for the SP model) and high likelihoods of low CPUE (37%) and stock below *Bmin* (15%) in the CP model. Mean commercial is about 345 t, and mean CPUE is between 1.5 and 2.0 kg/potlift.

The SP model was acceptable until TACC exceeded 300 t, when the collapse rate exceeded 1%. With respect to nLTBmin and nLT15, TACCs of 350 were acceptable. The CP model failed a 5% threshold on nLT15 above 200 t, failed against *Bmin* above 300 t, but for most other indicators was acceptable up through 350 t.

When Rule 4 was used, the SP model rebuilt the stock to *Bmsy* with a multiplier of 150, giving a mean catch of over 600 t. Rules failed against nLT15 above a multiplier of 200, and above 250 for nLTBmin and the collapse rate.

The CP model failed the low CPUE threshold above multiplier 100, against *Bmin* near 250, but did not collapse much until a multiplier of 500. Mean catch was maximised with a high multiplier of 700.

Differences in model performance are seen clearly in Figure 35. Mean catch vs fishing intensity is dome-shaped for the SP model but not for the CP model. For all but high fishing intensities, biomass in 2059 is higher for the SP model. The figure shows the higher tendency of the CP model to go below *Bmin* under constant TACC, but under Rule 4 the two models are nearly the same. The collapse rate is much higher for the SP model under both harvest control rules. The CP model is more likely to have CPUE less than 1.5 kg/potlift.

Figure 36 compares two indicators vs mean catch for the two models. For the CP model, nLTBmin increases continuously with mean catch. However, for the SP model this relation is not as simple, because the same mean catch can be taken under low or high fishing pressure. Thus, nLTBmin is zero over a range of increasing catches, and rises as mean catch decreases. Similarly for meanCPUE, reflecting the surplus production function. Under the CP rule, the relation between mean catch and mean CPUE is a nearly straight line, and nearly the same for the two harvest control rules.

Figure 36 suggests that, under the CP model, a rule could aim for mean CPUE near 3 kg/potlift (twice the current value), and expect a mean catch near 325 t. Mean CPUE of 3 under the SP model is associated with a much higher mean catch of about 600 t.

The higher propensity for collapse of the SP model is seen in the runs in Figure 37, where the same Rule 4 produced a much better result in the CP model, while the SP model had two collapses. However, the same constant catch led to increased biomass for the SP model but decreased biomass for the CP model.

9. INTERMEDIATE RUNS

Based on results of the preliminary explorations described above, a set of intermediate runs was made with Rule 4. The harvest control rule parameters used to define the rules were as follows.

name	par	value 1	value 2	value 3	value 4	value 5	value 6
rule type	1	4					
target catch	2	250000	300000	350000	400000	450000	500000
target CPUE	3	2					
shape	4	1					
shutdown threshold	5	0.0	0.5	1.0			
plateau left threshold	6	15	4				
plateau right threshold	7	17					
upper slope	8	60000					
minimum change	9	0.001					
maximum change	10	5					
latent year switch	11	0					

Five different values were used for the target catch, which determines the slope, three values were used for the shutdown threshold, and two values for the plateau (one established a plateau above kg/potlift while the other was so large as to essentially exclude a plateau). The target CPUE was fixed at 2; the shape was linear; minimum and maximum changes were so small and large respectively that they did not operate, and the latent year switch was turned off.

The combinations of this set of parameters defined 36 rules. Each rule was run with both the CP and SP operating models, and indicator summaries were calculated. These runs are summarised in several ways. The effects of the target catch, shutdown threshold and left plateau threshold values are explored, by averaging across all runs for each value of the parameter of interest, in Table 11 through Table 13, using six key parameters. The effect of varying target catch on these six key indicators is also shown in Figure 38. The relation between mean catch and three key indicators is shown in Figure 39.

Only two rules showed any collapse, each with 4 collapses in 2000 runs. Collapse is therefore not discussed further.

Rules delivered much higher biomass and catch under the SP model than under the CP model, as one would expect from the *MSY* and *Bmsy* results of the SP model. Because of this, the *Bmin* and low CPUE indicators were much lower in the SP model runs.

The relation between mean CPUE and mean catch, a key trade-off, was a simple declining function in the CP model runs (Figure 39), but a more complex function for the SP model runs. The relation is essentially the SP function turned on its side, with high catch resulting from an intermediate level of CPUE, and lower catch resulting from higher or lower CPUE.

For both operating models, higher target catch values (Table 11) are associated with lower mean CPUE and lower CPUE in 2059, and more years with low CPUE or biomass below *Bmin*. For the SP model runs, increasing target catch had the complex effect described above, with mean catch being maximised at a value of 350 t. For the CP model runs, higher target catch produced a higher mean catch, but the highest values produced very high numbers of years with low CPUE.

The shutdown threshold value (Table 12) had little effect on mean catch. In the SP model runs, higher values resulted in lower mean CPUE and CPUE in 2059, but had the unexpected effect of reducing the low biomass and low CPUE indicators. In the CP model runs, higher values also reduced these two indicators but had little effect on mean CPUE. For both models, higher values increased average annual variation (AAV) substantially, a classic trade-off between stability and safety. For the CP model, a value of 1 kg/potlift for this parameter gave minimum TACCs less than 100 t, whereas a value of 0.5 gave minimum TACCs between 128–154 t and a value of zero gave 158 and 208 t.

The left plateau threshold (Table 13) had little effect on the CP model runs, probably because it was rarely invoked. In the SP model, having a plateau starting at 4 kg/potlift reduced mean catch, decreased AAV and increased CPUE.

10. FINAL RUNS

From the 36 runs made in the intermediate series, six were chosen as parents for testing further variants. In choosing the six, some screening was used to eliminate rules.

Rules with multipliers of 250, 300 or 350 t were eliminated as being too low to have credibility, giving a TACC of 183, 220 and 257 t respectively (using a shutdown threshold of 0.5 kg/potlift) from a CPUE of 1.6 kg/pot, near the current level.

Two rules were screened out because biomass was less than *Bmin* in more than 5% of years; eight were screened out because they gave a minimum TACC of less than 100 t. Rules with a shutdown threshold of zero were screened out. This screening left the six parent rules used in this section.

Although the range of target catch parameter values seemed adequate for the SP model, it was arguably too short for the CP model, and having a rule that gave the current TACC at the current CPUE was desirable for comparison. Four parent rules were therefore added, with target catch values of 550 and 600 t, with and without a plateau beginning at 4 kg/potlift.

Each of the ten rules was run with the parameter combinations shown below. For all rules, the plateau right parameter was large, making the upper slope parameter meaningless; the minimum change was 10% (increased from the intermediate runs); shutdown threshold was 0.5 and shape was fixed at 1. The latent year switch could take three values and the maximum change threshold could take two, making six combinations of the parameters for each parent rule and giving a total of 60 final rules.

name	par	value 1	value 2	value 3	value 4	value 5
rule type	1	4				
target catch	2	400000	450000	500000	550000	600000
Target CPUE	3	2				
shape	4	1				
shutdown threshold	5	0.5				
plateau left threshold	6	15	4			
plateau right threshold	7	17				
upper slope	8	60000				
minimum change	9	10%				
maximum change	10	500%	35%			
latent year switch	11	0	1	2		

Using the CP model, major trades-off are shown in Figure 40. These runs suggest that an average catch roughly the same as the current catch could be taken from a higher stock size, near 2 kg/potlift, or that a somewhat higher catch could be taken from the current stock size, near 1.6 kg/potlift. The pattern of CPUE in 2059 is similar to that seen in the mean CPUE.

Rules that give a mean catch much higher than 375 t begin to have a risk of biomass less than the *Bmin* reference level. The rate of CPUE falling below 1.5 kg/pot ranges from about 15% with low average catch to 60% at the highest mean catch levels. There is a weak tendency for AAV to be higher with higher mean catch.

Because the design of the 60 rules was balanced, the effects of individual parameters could be explored. The effect of target catch is shown in Table 14. The *B<Bmin* indicator is lower in the SP model; however, in the CP model it reaches 5% only in with the highest target catch. Collapse reaches nearly 10% in the SP model under the highest target catch, but is below 5% in all the others. There were no collapses at all in the CP model.

Mean catch decreases with increasing values in the SP model, but increases in the CP model. A target catch of 500 or 550 t at a target CPUE of 2 kg/potlift gives a mean catch slightly higher than the current level, and mean CPUE near the current value of 1.6 kg/potlift; thus rules with these multipliers are roughly close to the status quo.

Mean CPUE declines in both models, but is higher for the SP model. The low CPUE indicator increases with target catch in both models, and is higher for the CP model. AAV is higher in the SP model and declines with increasing target catch, but increases in the CP model.

There was almost no effect of having a plateau for either model (Table 15), except that collapse in the SP model decreased by 5% with a plateau.

The effect of the maximum change threshold was very different in the two models (Table 16). For the SP model runs, a 35% maximum change rule increased the *B<Bmin* indicator by 38% but decreased the collapse rate by 9%. There was only a 1% change in AAV. For the CP model, the AAV was decreased by 36%. Minimum catch and TACC were increased by about 20%, and the low CPUE indicator decreased by 10%.

The latent year switch had large effects (Table 17). Most collapses (280 out of 296) in the SP model came from rules with a latent year, and the asymmetric latent year reduced collapses to 4 from 12 with no latent year. In both models the latent year strongly increased the *B<Bmin* indicator, and the asymmetric latent year strongly reduced it. Both latent year types reduced AAV, the asymmetric not as much as the ordinary latent year.

The 60 rules are summarised for key indicators in Table 18.

11. DISCUSSION

The simple analysis based on CPUE suggests that a large standing stock in CRA 6 was decreased sharply in the first few years of the fishery, and has remained relatively low ever since. The exploitation rate reached nearly 60% in 1969, but has fluctuated between 20 and 30% since 1971.

The analysis assumes that CPUE is a linear index of abundance. It is possible that the sharp decline in CPUE in 1969 and 1970 may instead reflect hyperdepletion, where the most abundant segments of the stock are fished down first, causing CPUE to decline more steeply than the stock size. But the late 1960s catches were extremely high – much higher than the current catches from all of New Zealand – and so the linear index alternative remains tenable. The limited range of stock sizes after the mid 1970s means that non-linearity in the index would be of little consequence to the assessment models.

The two operating models interpret the data quite differently. The CP model implies that production has been constant, near 380 t, over most of the history of the fishery. Predictions from the CP model have some uncertainty caused by the lack of contrast in biomass after the first few years of the fishery. Under this model, the mean catch could be increased slightly from its current level, and CPUE could be increased by allowing the stock to increase with a suitably conservation-oriented harvest control rule.

In contrast, the SP model implies that the stock is about half *Bmsy* and that yields could be doubled by rebuilding the stock to *Bmsy*. However, these predictions are also hampered by the lack of contrast in biomass after the first few years of the fishery.

It is hard to know which model is more realistic. Both models fit the data about equally well, although the SP model performed less well in McMC simulations than the CP model.

The assumptions underlying the SP model seem suspect, given that the size structure of the stock has not behaved as one would have expected with this type of model. The assumption of constant production must also be somewhat suspect.

Because the CP model is more conservative in its predictions, it seems safer to compare rules first on the basis of CP model results, and only then on the basis of SP model results. A defensible strategy might be to try to improve CPUE from its recent levels, and at the same time test how productivity responds to an increased stock size.

This work has provided some insight into the effects of rule parameters on the behaviour of different rules. However, the work is now at the stage where input is needed from the CRA 6 stakeholders. This is because the major trades-off have been identified and exemplified among the various final rules, but the decision about what targets are desirable and what direction should be taken on a specific trade-off are a matter for stakeholders. For instance, what target level of CPUE would be desirable for CRA 6? How is stability valued relative to catch or abundance? Are stakeholders willing to set aside some catch in the short term for possible gains in abundance in the longer term?

After the necessary input is obtained, further testing, including robustness testing, should be carried out with a small selection of final candidates.

12. ACKNOWLEDGMENTS

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Table 1: Numbers of fish measured in voluntary logbooks, 2001-2008, and the median sizes.

	Numbers			Median size	
Year	Males	Females	Total	Males	Females
2001	14	30	44	84	82
2002	362	307	669	74	80
2003	388	481	869	69	70
2004	504	621	1125	74	74
2005	1452	1416	2868	59	65
2006	1226	884	2110	64	64
2007	1368	1427	2795	64	67
2008	352	308	660	68	68
Total	5666	5474	11140		

Table 2: Commercial catch, total catch and CPUE for CRA 6.

Year	Commercial catch	Total catch	TACC	Arithmetic kg/day	Standardised kg/pot
1965	5415	15415		75	
1966	1465366	1475366		883	
1967	3084599	3094599		986	
1968	6346989	6356989		624	
1969	4291377	4301377		292	
1970	1729285	1739285		172	
1971	1124859	1134859		147	
1972	937494	947494		175	
1973	944676	954676		162	
1974	518000	528000		126	
1975	331000	341000		99	
1976	391000	401000		142	
1977	303000	313000		82	
1978	397578	407578		66	
1979	400320	410320		138	2.164
1980	355883	365883		135	1.999
1981	465366	475366		132	2.271
1982	471669	481669		106	1.639
1983	547699	557699		122	1.607
1984	491962	501962		116	1.283
1985	603633	613633		121	1.357
1986	580313	590313		137	1.491
1987	448495	458495		134	1.276
1988	450151	460151		112	1.254
1989	318348	328348		106	1.140
1990	369689	379689	518.2	89	1.165
1991	388285	398285	503.0	87	1.209
1992	329417	339417	503.0	91	1.174
1993	341784	351784	530.6		1.062
1994	312544	322544	530.6		1.027
1995	315340	325340	530.6		1.046
1996	378277	388277	530.6		1.114
1997	338671	348671	400.0		1.049

Year	Commercial catch	Total catch	TACC	Arithmetic kg/day	Standardised kg/pot
1998	334244	344244	360.0		1.291
1999	322357	332357	360.0		1.344
2000	342697	352697	360.0		1.208
2001	328660	338660	360.0		1.196
2002	336316	346316	360.0		1.277
2003	290396	300396	360.0		1.210
2004	322960	332960	360.0		1.376
2005	351707	361707	360.0		1.471
2006	352100	362100	360.0		1.665
2007	354667	364667	360.0		1.617
2008	352564	362564	360.0		1.607

Table 3: Lower (lb) and upper (ub) bounds for each estimated parameter in the surplus production model. The same bounds were used for the parameters in common with the constant production model.

Parameter	lb	ub
$B0$	5.00E+04	1.00E+08
r	0.01	1.5
p	0.01	5
$\ln\left(q_{day}\right)$	-20	-3
$\ln\left(q_{pot}\right)$	-20	-3
σ_{day}	0.1	2
σ_{pot}	0.1	2

Table 4: Summaries of posterior distributions (5th and 95th quantiles, mean and median) of estimated and derived parameters from the McMC for the surplus production model; sdnr is the standard deviation of normalised residuals. Biomass and yields shown in kg.

Quantity	5%	Median	Mean	95%
Function value	53.88	56.41	56.69	60.51
Likelihood for kg/day	69.01	69.82	70.17	72.56
Likelihood for kg/pot	-15.78	-13.68	-13.48	-10.31
B0	18071025	18724550	18730874	19497515
r	0.104	0.120	0.121	0.138
p	0.3	0.3	0.3	0.3
$\ln\left(q_{day}\right)$	-10.15	-9.97	-9.97	-9.78
$\ln\left(q_{pot}\right)$	-14.47	-14.26	-14.26	-14.07
σ_{day}	0.190	0.267	0.277	0.401
σ_{pot}	0.059	0.083	0.089	0.136
sdnr(kg/day)	0.615	0.915	0.925	1.285
sdnr2(kg/potlift)	0.872	1.468	1.454	2.062
B2008	2049943	2485325	2503755	3021482
B08/B0	0.112	0.133	0.133	0.156
Bmin	1167418	1404320	1411183	1681410

Quantity	5%	Median	Mean	95%
Bmsy	7536519	7809080	7811724	8131446
B08/Bmsy	0.270	0.318	0.320	0.375
MSY	649338	722710	724839	799681
CSP	414211	455814	453488	486443
B08/Bmin	1.507	1.767	1.783	2.098

Table 5: Summaries of posterior distributions (5th and 95th quantiles, mean and median) of estimated and derived parameters from the McMC for the constant production model; sdnr is the standard deviation of normalised residuals. Biomass and yields in kg.

	5%	Median	Mean	95%
Function value	52.26	54.42	54.77	58.36
Likelihood for kg/day	69.25	70.10	70.45	72.88
Likelihood for kg/pot	-17.44	-15.98	-15.68	-12.86
B0	19034385	19403600	19436666	19949905
constantP	368120	375764	375838	383682
$\ln\left(q_{day}\right)$	-10.31	-10.13	-10.13	-9.96
$\ln\left(q_{pot}\right)$	-14.35	-14.14	-14.14	-13.95
σ_{day}	0.194	0.273	0.284	0.410
σ_{pot}	0.084	0.106	0.108	0.138
sdnr(kg/day)	0.609	0.907	0.920	1.276
sdnr2(kg/potlift)	0.763	0.978	0.988	1.239
B2008	1698232	2029500	2053103	2465174
B08/B0	0.0886	0.1048	0.1055	0.1249
Bmin	1174829	1409410	1427868	1728135
B08/Bmin	1.338	1.434	1.440	1.549

Table 6: Standard deviation from two periods, and autocorrelation, of production deviations from the two models.

	SP model	CP model
Std dev 1966-2007	1021816	1296436
Std dev 1979-2007	240728	216620
Autocorrelation 1979-2007	-0.278	-0.305

Table 7: Summaries of indicators for various constant catches (t) from exploratory runs with the surplus production model. The bottom three lines show the indicators are rates (collapse as number per set of runs; the others as number per year).

Indicator	0	50	100	150	200	250	300	350	400	450	500	600	700
nLTBmin	0.00	0.00	0.00	0.00	0.01	0.06	0.29	1.33	4.10	9.59	18.62	35.30	42.74
nLTBmsy	8.503	9.1965	10.004	11.0015	12.2525	13.908	16.3055	19.926	25.382	32.7115	40.5195	48.83	49.986
Collapse	0	0	0	0	0	2	13	67	216	510	991	1764	1987
minTACC	0	50000	100000	150000	200000	250000	300000	350000	400000	450000	500000	600000	700000
meanCatch	10000	60000	110000	160000	210000	259929	309256	355206	390609	404525	382914	293855	238136
meanC/MSY	0.013	0.077	0.142	0.206	0.271	0.335	0.399	0.458	0.504	0.522	0.494	0.379	0.307
minCatch	10000	60000	110000	160000	210000	259741	307990	347842	365289	342468	257156	71328	4663
minCPUE	1.70	1.69	1.68	1.66	1.64	1.62	1.58	1.51	1.38	1.14	0.78	0.19	0.01
meanCPUE	9.22	8.89	8.54	8.16	7.75	7.28	6.72	6.00	5.02	3.80	2.47	0.81	0.36
nLT15	0	0	0	1	1	1	1	3	7	13	23	40	46
B(59)	18794650	18351000	17885250	17391750	16857350	16253710	15487282	14277338	12298254	9353031	5706609	1113638	202239
B(59)/Bmsy	2.41	2.35	2.29	2.23	2.16	2.08	1.98	1.83	1.58	1.20	0.73	0.14	0.03
CPUE (59)	12.15	11.86	11.57	11.25	10.91	10.52	10.04	9.28	8.01	6.08	3.72	0.72	0.13
AAV	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
<Bmin rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%	2.7%	8.2%	19.2%	37.2%	70.6%	85.5%
collapse rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.7%	3.4%	10.8%	25.5%	49.6%	88.2%	99.4%
CPUE <1.5 rate	1%	1%	1%	1%	1%	2%	3%	6%	13%	26%	46%	80%	92%

Table 8: Summaries of indicators for various Rule 4 par2 multipliers from exploratory runs with the surplus production model. See caption for Table 7.

Indicator	0	50	100	150	200	250	300	350	400	450	500	600	700
nLTBmin	0.00	0.00	0.00	0.00	0.02	0.42	5.52	18.61	30.31	37.23	40.96	44.44	45.88
nLTBmsy	8.503	10.6555	15.3415	40.3695	49.87	50	50	50	50	50	50	50	50
collapse	0	0	0	0	0	4	95	476	1085	1532	1797	1960	1991
minTACC	0	76742	152126	224454	288564	303496	221412	116733	48807	17523	6082	1143	588
meanCatch	10000	360971	548168	618412	610482	555049	475830	395802	334099	293017	266489	237077	222974
meanC/MSY	0.013	0.466	0.708	0.798	0.788	0.716	0.613	0.510	0.430	0.377	0.343	0.305	0.287
minCatch	10000	86742	162126	234454	298564	313477	230953	124134	53194	19759	7258	1646	1004
minCPUE	1.70	1.68	1.65	1.61	1.51	1.23	0.73	0.33	0.12	0.04	0.01	0.00	0.00
meanCPUE	9.22	7.17	5.48	4.12	3.04	2.19	1.55	1.09	0.80	0.62	0.51	0.38	0.32
nLT15	0	0	1	1	1	6	24	39	45	47	48	49	49
B(59)	18794650	14275900	10595095	7653260	5354355	3599129	2297745	1445252	985401	742641	602867	454748	383378
B(59)/Bmsy	2.41	1.83	1.36	0.98	0.68	0.46	0.29	0.18	0.13	0.09	0.08	0.06	0.05
CPUE (59)	12.15	9.22	6.83	4.92	3.43	2.30	1.46	0.92	0.62	0.47	0.38	0.29	0.24
AAV	2%	20%	19%	19%	18%	19%	35%	106%	247%	393%	539%	752%	908%
<Bmin rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	11.0%	37.2%	60.6%	74.5%	81.9%	88.9%	91.8%
collapse rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	4.8%	23.8%	54.3%	76.6%	89.9%	98.0%	99.6%
CPUE <1.5 rate	1%	1%	1%	1%	3%	12%	48%	78%	89%	94%	96%	97%	98%

Table 9: Summaries of indicators for constant catches (t) from exploratory runs with the constant production model. See caption for Table 7.

Indicator	0	50	100	150	200	250	300	350	400	450	500	600	700
nLTBmin	0.02	0.03	0.03	0.04	0.06	0.19	1.14	7.20	22.65	35.83	42.04	45.85	47.12
collapse	0	0	0	0	0	0	0	17	82	173	252	326	346
minTACC	0	50000	100000	150000	200000	250000	300000	350000	400000	450000	500000	600000	700000
meanCatch	10000	60000	110000	160000	210000	260000	309951	358325	394631	408436	411444	412596	412931
minCatch	10000	60000	110000	160000	210000	260000	308807	332291	247011	123745	74983	58995	55770
minCPUE	1.43	1.41	1.39	1.37	1.34	1.28	1.18	0.90	0.42	0.14	0.07	0.06	0.05
meanCPUE	8.10	7.21	6.32	5.43	4.54	3.65	2.76	1.90	1.18	0.77	0.60	0.49	0.45
nLT15	1.011	1.14	1.3255	1.628	2.196	3.465	7.272	18.7455	35.558	44.581	47.437	48.767	49.149
B(59)	20289800	17839700	15389780	12939440	10490455	8039575	5592204	3221814	1434243	744162	592023	535830	519859
CPUE (59)	14.69	12.91	11.13	9.36	7.58	5.80	4.02	2.31	1.02	0.53	0.43	0.39	0.38
AAV	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
<Bmin rate	0.0%	0.1%	0.1%	0.1%	0.1%	0.4%	2.3%	14.4%	45.3%	71.7%	84.1%	91.7%	94.2%
collapse rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	4.1%	8.7%	12.6%	16.3%	17.3%
CPUE <1.5 rate	2%	2%	3%	3%	4%	7%	15%	37%	71%	89%	95%	98%	98%

Table 10: Summaries of indicators for Rule 4 multipliers from exploratory runs with the constant production model. See caption for Table 7.

Indicator	0	50	100	150	200	250	300	350	400	450	500	600	700
nLTBmin	0.02	0.03	0.03	0.06	0.37	3.03	10.72	21.66	31.53	38.16	41.80	44.85	46.11
collapse	0	0	0	0	0	0	0	1	4	11	25	64	103
minTACC	0	65471	128663	183056	207615	204265	191039	174319	155691	136743	120060	96092	82769
meanCatch	11994	241229	320671	354116	371381	381773	388701	393649	397354	400215	402460	405649	407689
minCatch	10000	75471	138663	193056	217615	214265	201039	184314	165630	146560	129677	105164	91096
minCPUE	1.43	1.40	1.36	1.26	1.04	0.81	0.63	0.50	0.39	0.30	0.24	0.16	0.12
meanCPUE	8.09	4.72	3.15	2.31	1.81	1.49	1.26	1.09	0.96	0.86	0.77	0.66	0.58
nLT15	1.01	1.21	1.61	3.43	12.74	27.92	38.78	44.22	46.75	47.91	48.51	49.07	49.28
B(59)	20209300	9050475	5121625	3453680	2590544	2070670	1723954	1476282	1290742	1147495	1035070	874838	772638
CPUE (59)	14.62	6.49	3.66	2.47	1.85	1.48	1.23	1.05	0.92	0.82	0.74	0.63	0.55
AAV	4.2%	19.7%	19.2%	19.0%	19.1%	19.8%	21.1%	23.2%	25.9%	29.7%	36.5%	53.2%	69.0%
<Bmin rate	0.0%	0.1%	0.1%	0.1%	0.7%	6.1%	21.4%	43.3%	63.1%	76.3%	83.6%	89.7%	92.2%
collapse rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.6%	1.3%	3.2%	5.2%
CPUE <1.5 rate	2%	2%	3%	7%	25%	56%	78%	88%	94%	96%	97%	98%	99%

Table 11: Exploring the effects of rule parameters in intermediate runs with both models (surplus production (upper) and constant production (lower): the effect of target catch (rule par 2).

Model	par 2	nLTBmin	meanCatch	MeanCPUE	nLT15	AAV	CPUE(59)
SP	250	0.001	577896	4.57	0.55	18%	5.84
SP	300	0.002	606263	3.82	0.63	20%	4.67
SP	350	0.004	611779	3.22	0.79	23%	3.70
SP	400	0.009	599638	2.77	1.21	29%	3.01
SP	450	0.036	578425	2.42	2.39	28%	2.55
SP	500	0.162	553908	2.14	5.30	33%	2.20
CP	250	0.033	346764	2.54	1.95	28%	2.72
CP	300	0.042	357202	2.25	3.21	30%	2.35
CP	350	0.073	364619	2.03	5.95	32%	2.09
CP	400	0.192	370180	1.86	10.42	35%	1.89
CP	450	0.554	374499	1.72	15.88	40%	1.73
CP	500	1.394	377964	1.61	21.37	43%	1.61

Table 12: Exploring the effects of rule parameters in intermediate runs with both models (surplus production (upper) and constant production (lower): the effect of the shutdown threshold (rule par 5).

Model	par 5	nLTBmin	meanCatch	MeanCPUE	nLTI15	AAV	CPUE(59)
SP	0.0	0.090	578075	3.56	2.02	16%	4.40
SP	0.5	0.013	591563	3.19	1.70	21%	3.69
SP	1.0	0.004	594317	2.73	1.70	39%	2.89
CP	0.0	0.799	364577	1.99	12.20	19%	2.09
CP	0.5	0.249	365206	2.00	9.76	27%	2.06
CP	1.0	0.095	365831	2.01	7.42	57%	2.04

Table 13: Exploring the effects of rule parameters in intermediate runs with both models (surplus production (upper) and constant production (lower): the effect of the left plateau threshold (rule par 6).

Model	par 6	nLTBmin	meanCatch	MeanCPUE	nLTI15	AAV	CPUE(59)
SP	4	0.036	577359	3.27	1.81	23%	3.96
SP	15	0.036	598611	3.04	1.81	27%	3.36
CP	4	0.381	365173	2.00	9.80	35%	2.07
CP	15	0.381	365237	2.00	9.80	35%	2.06

Table 14: The effect of the target catch parameter in final runs, averaged across all runs with that parameter. SP: surplus production model; CP: constant production model.

		Target catch				
Model	Mndicator	400000	450000	500000	550000	600000
SP	nLTBmin	0.011	0.024	0.105	0.351	0.946
SP	collapse	1	3	25	75	192
SP	meanCatch	609592	588017	564481	541009	518946
SP	mean CPUE	2.88	2.53	2.25	2.03	1.85
SP	nLT15	1.08	1.98	4.32	8.45	13.67
SP	CPUE(59)	3.07	2.64	2.31	2.05	1.84
SP	AAV	15%	16%	17%	18%	20%
SP	B59/Bmsy	61%	53%	46%	41%	37%
CP	nLTBmin	0.189	0.428	0.955	1.863	3.191
CP	meanCatch	368449	372754	376204	379026	381357
CP	mean CPUE	1.91	1.78	1.66	1.57	1.49
CP	nLT15	9.33	14.14	19.17	23.76	27.77
CP	CPUE(59)	1.95	1.80	1.67	1.57	1.49
CP	AAV	18%	19%	20%	21%	23%

Table 15: The effect of having a plateau starting at 4 kg/potlift compared with having no plateau (plateau left parameter set at 15) in final runs. The percentage change is the mean of (value obtained with the plateau divided by the value obtained without the plateau) minus 1. Collapse is measured as the change in the sum of collapsed runs. SP: surplus production model; CP: constant production model.

Model	Indicator	Change
SP	B<Bmin	-2%
SP	collapse	-5%
SP	minTACC	0%
SP	meanCatch	0%
SP	minCatch	0%
SP	minCPUE	0%
SP	meanCPUE	0%
SP	CPUE<1.5	0%
SP	B59	0%
SP	CPUE59	0%
SP	AAV	-1%
SP	B<Bmsy	0%
SP	meanC/MSY	0%
SP	B59/Bmsy	0%
CP	B<Bmin	0%
CP	minTACC	0%
CP	meanCatch	0%
CP	minCatch	0%
CP	minCPUE	0%
CP	meanCPUE	0%
CP	CPUE<1.5	0%
CP	B59	0%
CP	CPUE59	0%
CP	AAV	0%

Table 16: The effect of having a 35% maximum change threshold compared with having a 500% threshold in final runs. The percentage change is (the value obtained with 35% divided by the value obtained with 500%) minus 1. Collapse is measured as the change in the sum of collapsed runs. SP: surplus production model; CP: constant production model.

Model	Indicator	Change
SP	B<Bmin	38%
SP	collapse	-9%
SP	minTACC	0%
SP	meanCatch	0%
SP	minCatch	0%
SP	minCPUE	0%
SP	meanCPUE	0%
SP	CPUE<1.5	0%
SP	B59	0%
SP	CPUE59	0%
SP	AAV	-1%
SP	B<Bmsy	0%
SP	meanC/MSY	0%
SP	B59/Bmsy	0%
CP	B<Bmin	0%
CP	minTACC	23%
CP	meanCatch	0%
CP	minCatch	21%
CP	minCPUE	1%
CP	meanCPUE	3%
CP	CPUE<1.5	-10%
CP	B59	4%
CP	CPUE59	4%
CP	AAV	-36%

Table 17: The effect of having a latent year (switch 1) or asymmetric latent year (switch 2) compared with having no latent year in final runs. The percentage change is (the value obtained with latent switch 1 or 2 divided by the value obtained no latent year) minus 1. Collapse is measured as the change in the sum of collapsed runs. SP: surplus production model; CP: constant production model.

Model	Indicator	Latent 1	Latent 2
SP	B<Bmin	274%	-51%
SP	collapse	2233%	-67%
SP	minTACC	1%	11%
SP	meanCatch	0%	4%
SP	minCatch	1%	11%
SP	minCPUE	-6%	8%
SP	meanCPUE	1%	10%
SP	CPUE<1.5	13%	-38%
SP	CPUE59	1%	11%
SP	AAV	-34%	-27%
SP	meanC/MSY	0%	4%
SP	B59/Bmsy	1%	10%
CP	B<Bmin	67%	-40%
CP	minTACC	8%	11%
CP	meanCatch	0%	-1%
CP	minCatch	8%	10%
CP	minCPUE	-5%	6%
CP	meanCPUE	1%	7%
CP	CPUE<1.5	0%	-21%
CP	CPUE59	1%	7%
CP	AAV	-36%	-27%

Table 18: Summary of some key indicators from both models on the final 60 rules. SP: surplus production model; CP: constant production model. The B<Bmin indicator is shown as the percentage of years in which this was true, similarly the low CPUE indicator. Catches in tonnes.

					CP	CP	CP	CP	CP	CP	SP	SP	SP	SP	SP	SP	SP	SP
					B<	Mean	Mean	CPUE	CPUE		*B<*		Mean	Mean	CPUE	CPUE		*B59<*
Rule	p2	p6	p10	p11	*Bmin*	catch	CPUE	<1.5	2059	AAV	*Bmin*	coll	catch	CPUE	<1.5	2059	AAV	*Bmsy*
2901	400	4	0.35	0	0.3%	369	1.895	19.1%	1.928	19.7%	0.0%	0	608	2.833	2.1%	3.033	17.0%	61%
2904	400	4	0.35	1	0.7%	368	1.910	20.4%	1.952	11.8%	2.2%	0	611	2.898	124.0%	3.072	10.4%	61%
3201	400	4	0.35	2	0.2%	365	2.020	13.7%	2.061	13.9%	0.7%	0	620	3.085	86.6%	3.293	11.8%	66%
3204	400	4	5	0	0.3%	370	1.857	20.8%	1.885	26.6%	0.7%	0	603	2.769	111.1%	2.972	21.0%	59%
3501	400	4	5	1	0.6%	370	1.854	22.4%	1.883	17.3%	1.6%	0	604	2.785	130.2%	2.982	13.5%	59%
3504	400	4	5	2	0.2%	367	1.955	15.6%	1.991	20.5%	0.5%	0	614	2.970	88.2%	3.210	15.8%	64%
2001	400	15	0.35	0	0.3%	369	1.895	19.1%	1.928	19.7%	0.8%	0	607	2.813	104.6%	2.997	17.6%	60%
2004	400	15	0.35	1	0.7%	368	1.910	20.4%	1.952	11.9%	2.7%	1	609	2.861	127.2%	3.016	10.8%	60%
2301	400	15	0.35	2	0.2%	365	2.020	13.7%	2.061	13.9%	0.7%	0	620	3.056	87.0%	3.249	12.6%	65%
2304	400	15	5	0	0.3%	370	1.857	20.8%	1.885	26.6%	0.7%	0	603	2.746	111.5%	2.931	22.0%	59%
2601	400	15	5	1	0.6%	370	1.854	22.4%	1.882	17.3%	1.5%	0	602	2.749	131.7%	2.922	14.2%	58%
2604	400	15	5	2	0.2%	367	1.955	15.6%	1.991	20.5%	0.5%	0	614	2.941	88.2%	3.158	17.0%	63%
2902	450	4	0.35	0	0.7%	373	1.757	29.0%	1.775	20.2%	1.6%	0	585	2.483	196.1%	2.590	18.0%	52%
2905	450	4	0.35	1	1.5%	373	1.774	29.8%	1.800	12.1%	5.0%	1	588	2.537	232.7%	2.627	11.0%	52%
3202	450	4	0.35	2	0.4%	370	1.881	21.3%	1.907	14.1%	1.0%	0	602	2.723	126.9%	2.839	12.6%	57%
3205	450	4	5	0	0.7%	375	1.719	31.7%	1.730	28.1%	1.5%	0	580	2.418	220.1%	2.524	22.8%	50%
3502	450	4	5	1	1.3%	375	1.717	33.1%	1.732	18.8%	2.9%	0	580	2.427	261.9%	2.519	14.8%	50%
3505	450	4	5	2	0.5%	372	1.812	24.6%	1.831	21.7%	1.0%	0	594	2.608	144.0%	2.739	17.3%	55%
2002	450	15	0.35	0	0.7%	373	1.757	29.0%	1.775	20.2%	1.6%	0	585	2.479	196.7%	2.584	18.1%	52%
2005	450	15	0.35	1	1.5%	373	1.774	29.8%	1.800	12.1%	7.9%	2	587	2.527	238.0%	2.620	11.2%	52%
2302	450	15	0.35	2	0.4%	370	1.881	21.3%	1.907	14.1%	1.1%	0	602	2.717	127.4%	2.833	12.8%	57%
2305	450	15	5	0	0.7%	375	1.719	31.7%	1.730	28.1%	1.5%	0	579	2.413	220.7%	2.516	23.1%	50%
2602	450	15	5	1	1.3%	375	1.717	33.2%	1.732	18.8%	3.0%	0	579	2.417	266.0%	2.506	15.0%	50%
2605	450	15	5	2	0.5%	372	1.812	24.6%	1.831	21.7%	1.0%	0	594	2.601	144.4%	2.729	17.6%	54%
2903	500	4	0.35	0	1.6%	377	1.645	39.5%	1.654	20.8%	4.9%	1	561	2.211	430.2%	2.262	18.7%	45%
2906	500	4	0.35	1	3.2%	376	1.664	39.5%	1.678	12.5%	32.9%	10	563	2.258	513.3%	2.309	11.6%	46%
3203	500	4	0.35	2	0.9%	373	1.767	29.7%	1.785	14.5%	2.4%	0	582	2.443	247.9%	2.507	13.1%	50%
3206	500	4	5	0	1.8%	378	1.605	43.0%	1.606	29.8%	4.9%	0	555	2.144	506.2%	2.191	24.4%	44%
3503	500	4	5	1	2.9%	378	1.605	43.8%	1.609	20.1%	14.1%	0	555	2.150	585.6%	2.183	16.0%	44%
3506	500	4	5	2	1.0%	375	1.695	34.5%	1.703	23.1%	2.2%	0	572	2.324	303.2%	2.393	18.5%	48%
2003	500	15	0.35	0	1.6%	377	1.645	39.5%	1.654	20.8%	4.9%	1	561	2.210	430.7%	2.261	18.8%	45%

Rule	p2	p6	p10	p11	CP *B< Bmin*	CP Mean catch	CP Mean CPUE	CP CPUE <1.5	CP CPUE 2059	CP AAV	SP *B< Bmin*	SP coll	SP Mean catch	SP Mean CPUE	SP CPUE <1.5	SP CPUE 2059	SP AAV	SP *B59< Bmsy*
2006	500	15	0.35	1	3.2%	376	1.664	39.5%	1.678	12.5%	36.0%	13	563	2.253	520.6%	2.302	11.7%	46%
2303	500	15	0.35	2	0.9%	373	1.767	29.7%	1.784	14.5%	2.1%	0	582	2.440	248.3%	2.506	13.1%	50%
2306	500	15	5	0	1.8%	378	1.605	43.0%	1.606	29.8%	4.9%	0	555	2.142	506.9%	2.189	24.5%	44%
2603	500	15	5	1	2.9%	378	1.605	43.8%	1.609	20.1%	14.4%	0	554	2.147	589.1%	2.181	16.1%	44%
2606	500	15	5	2	1.0%	375	1.695	34.5%	1.702	23.1%	2.2%	0	572	2.322	304.0%	2.390	18.6%	48%
3701	550	4	0.35	0	3.5%	380	1.551	49.1%	1.554	21.5%	19.6%	1	538	1.992	861.1%	2.009	19.6%	40%
3702	550	4	0.35	1	5.7%	379	1.572	47.8%	1.580	12.8%	101.6%	33	538	2.033	964.2%	2.056	12.3%	41%
3703	550	4	0.35	2	2.0%	376	1.673	38.2%	1.686	14.9%	7.8%	1	561	2.219	495.5%	2.254	13.5%	45%
3704	550	4	5	0	3.6%	381	1.511	53.1%	1.505	31.9%	20.0%	1	530	1.922	1010.4%	1.933	26.4%	39%
3705	550	4	5	1	5.4%	381	1.513	52.9%	1.508	21.9%	51.7%	1	529	1.926	1109.3%	1.928	17.8%	39%
3706	550	4	5	2	2.2%	378	1.599	44.0%	1.597	24.7%	8.5%	0	550	2.094	624.1%	2.120	19.9%	42%
3901	550	15	0.35	0	3.5%	380	1.551	49.1%	1.554	21.5%	19.6%	1	538	1.991	861.5%	2.009	19.6%	40%
3902	550	15	0.35	1	5.7%	379	1.572	47.8%	1.580	12.8%	104.8%	34	538	2.031	969.0%	2.056	12.4%	41%
3903	550	15	0.35	2	2.0%	376	1.673	38.2%	1.685	14.9%	7.8%	1	561	2.218	496.0%	2.253	13.6%	45%
3904	550	15	5	0	3.6%	381	1.511	53.1%	1.505	31.9%	20.0%	1	530	1.922	1010.8%	1.933	26.4%	39%
3905	550	15	5	1	5.4%	381	1.513	52.9%	1.508	21.9%	52.1%	1	529	1.925	1111.1%	1.927	17.8%	39%
3906	550	15	5	2	2.2%	378	1.599	44.0%	1.597	24.7%	8.5%	0	549	2.093	624.6%	2.119	19.9%	42%
3801	600	4	0.35	0	6.2%	382	1.472	57.4%	1.471	22.2%	66.8%	2	516	1.813	1419.6%	1.810	20.6%	36%
3802	600	4	0.35	1	8.9%	381	1.494	55.0%	1.505	13.2%	237.0%	88	515	1.849	1472.8%	1.845	13.9%	37%
3803	600	4	0.35	2	3.6%	378	1.594	45.7%	1.603	15.4%	29.5%	1	542	2.039	867.7%	2.055	14.2%	41%
3804	600	4	5	0	6.5%	383	1.431	61.9%	1.420	36.0%	63.0%	1	507	1.743	1639.2%	1.731	29.0%	35%
3805	600	4	5	1	9.0%	383	1.433	60.8%	1.422	24.0%	140.0%	3	506	1.746	1705.2%	1.725	20.2%	34%
3806	600	4	5	2	4.1%	381	1.517	52.6%	1.510	27.0%	29.5%	0	528	1.907	1093.3%	1.903	21.7%	38%
4001	600	15	0.35	0	6.2%	382	1.472	57.4%	1.471	22.2%	66.8%	2	516	1.813	1419.6%	1.810	20.6%	36%
4002	600	15	0.35	1	8.9%	381	1.494	55.0%	1.505	13.2%	240.5%	90	515	1.847	1478.0%	1.844	13.9%	37%
4003	600	15	0.35	2	3.6%	378	1.594	45.7%	1.603	15.4%	29.3%	1	542	2.039	868.0%	2.055	14.2%	41%
4004	600	15	5	0	6.5%	383	1.431	61.9%	1.420	36.0%	63.0%	1	507	1.743	1639.4%	1.731	29.0%	35%
4005	600	15	5	1	9.0%	383	1.433	60.8%	1.422	24.0%	140.3%	3	506	1.745	1706.8%	1.725	20.3%	34%
4006	600	15	5	2	4.1%	381	1.517	52.6%	1.510	27.0%	29.5%	0	528	1.907	1094.1%	1.903	21.7%	38%

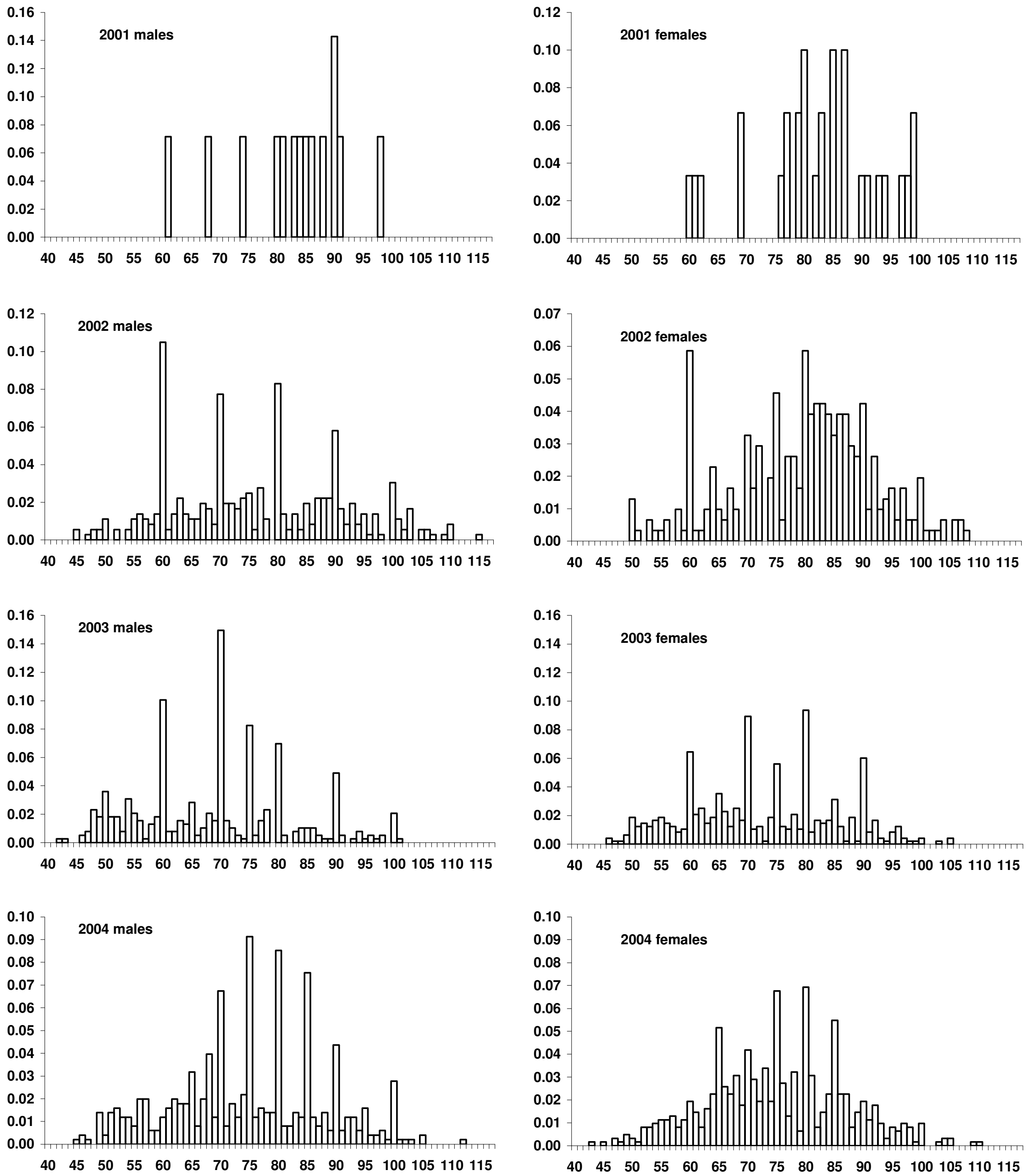

Figure 1: Tail width proportions-at-length for males and females from voluntary logbooks in CRA 6, 2001–2004. Scales have been adjusted so that, within a given year, males and females are on the same scale.

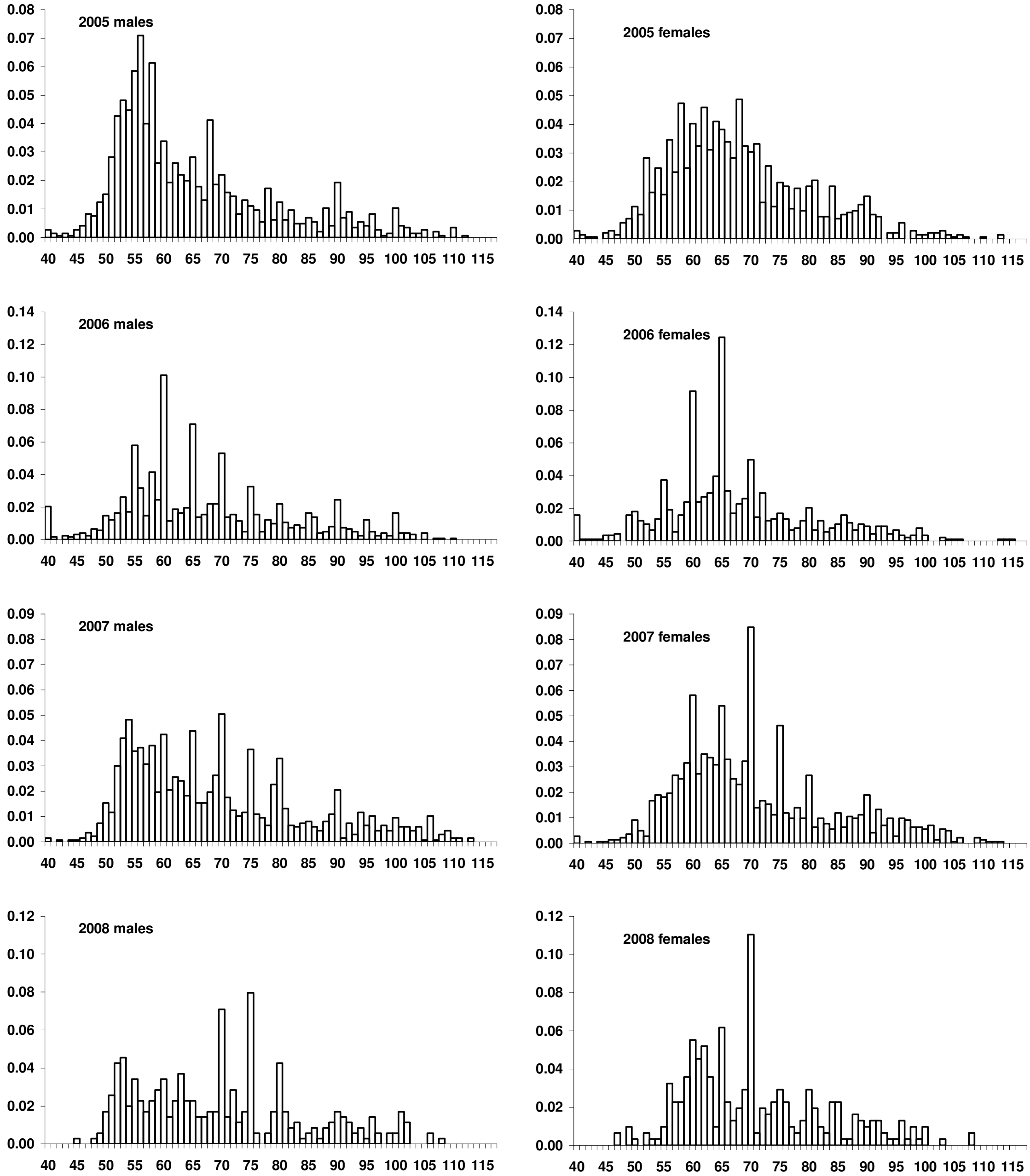

Figure 2: Tail width proportions-at-length for males and females from voluntary logbooks in CRA 6, 2005–2008. Scales have been adjusted so that, within a given year, males and females are on the same scale.

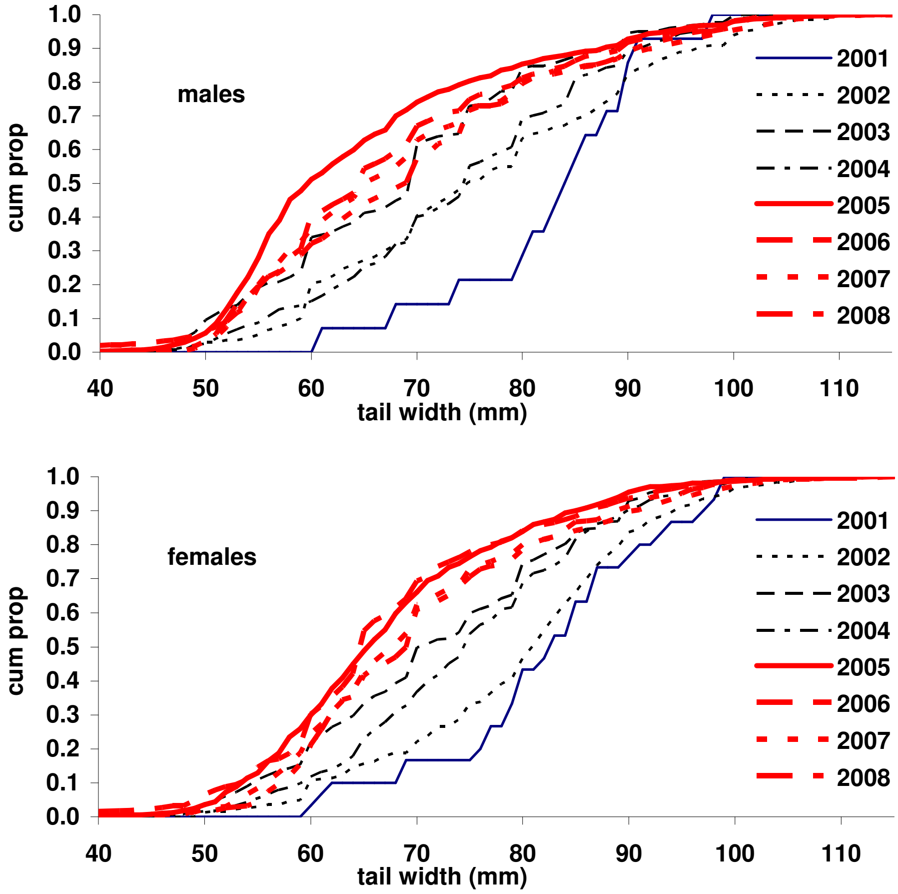

Figure 3: Cumulative proportions-at-length by year for CRA 6 voluntary logbook length frequencies.

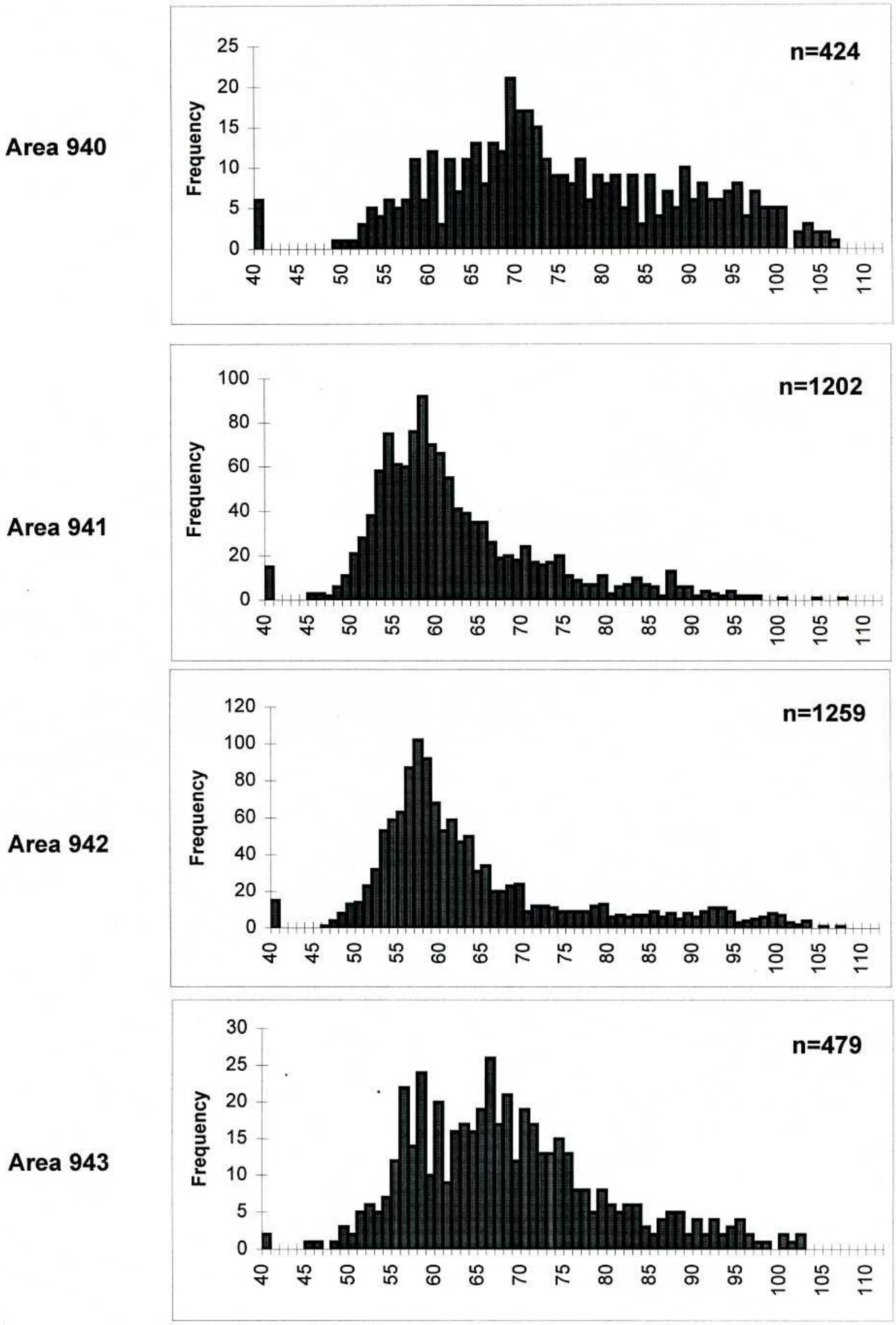

Figure 4: Tail width frequencies for males in the four statistical areas of CRA 6, 1995–96 (NIWA, unpublished data).

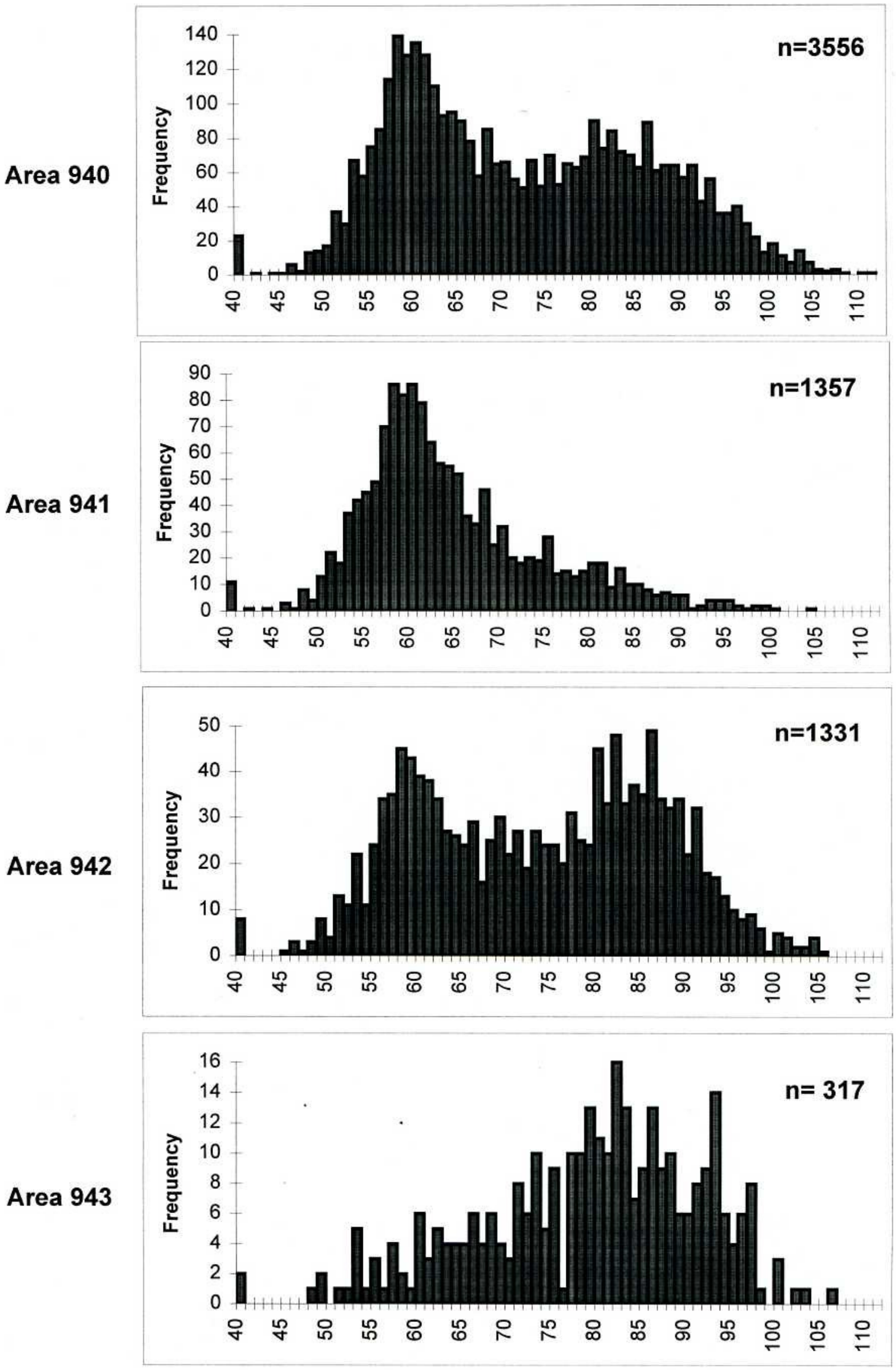

Figure 5: Tail width frequencies for females in the four statistical areas of CRA 6, 1995–96 (NIWA, unpublished data).

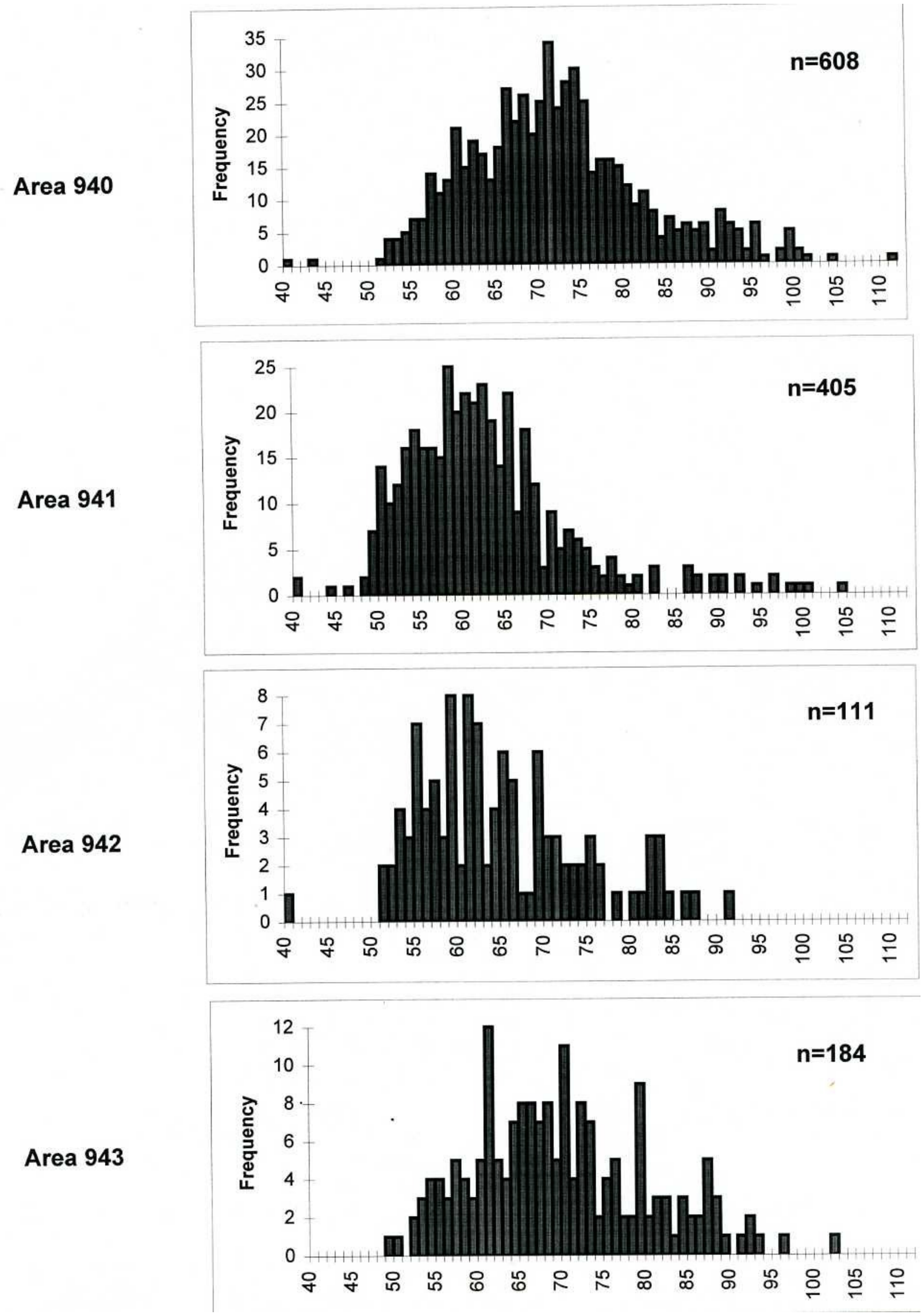

Figure 6: Tail width frequencies for males in the four statistical areas of CRA 6, 1996–97 (NIWA, unpublished data).

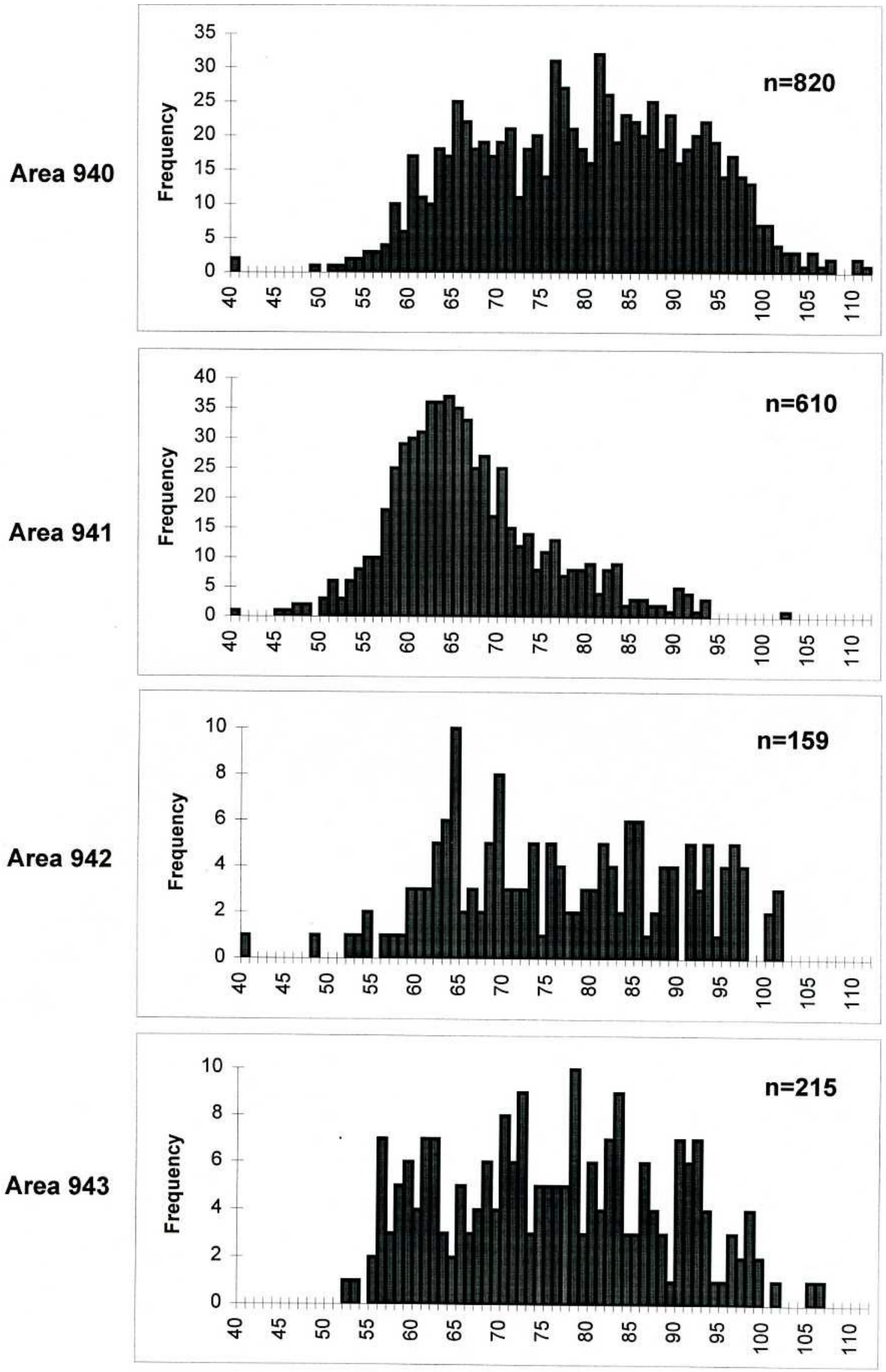

Figure 7: Tail width frequencies for females in the four statistical areas of CRA 6, 1996-97 (NIWA, unpublished data).

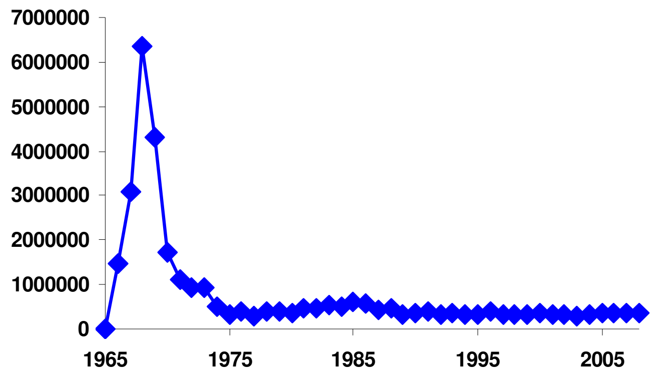

Figure 8: Commercial catch from CRA 6, 1965 to present.

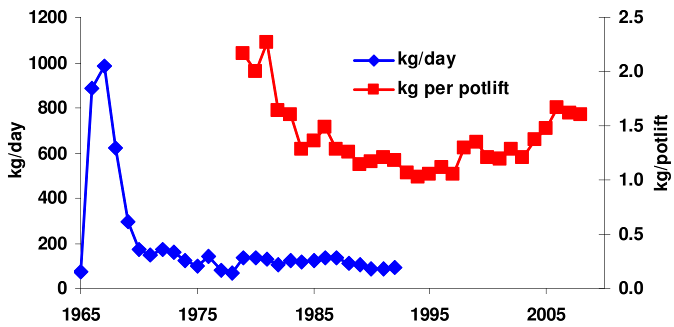

Figure 9: Catch per day (diamonds) and catch per potlift from CRA 6.

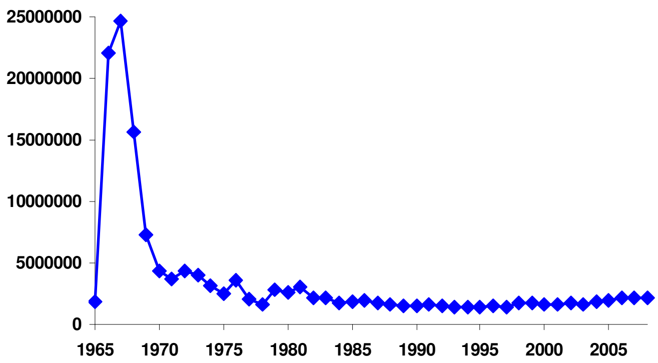

Figure 10: CRA 6 biomass estimated from the simple method described in the text.

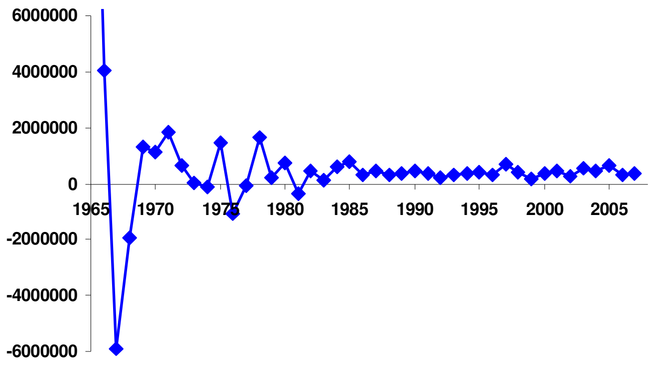

Figure 11: Annual CRA 6 production estimated from the simple method described in the text. The y-axis is truncated and the first value lies off the scale.

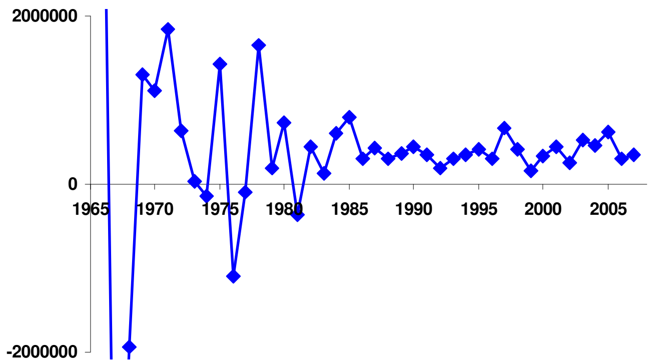

Figure 12: The same data as in Figure 11 with the y-axis truncated further to show variability in production after 1979.

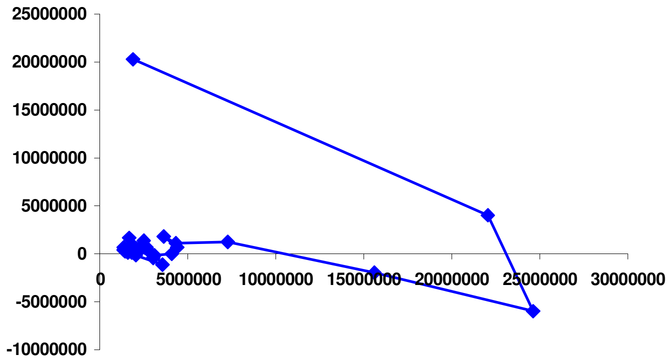

Figure 13: Estimated annual CRA 6 production plotted against estimated biomass, 1965–2008.

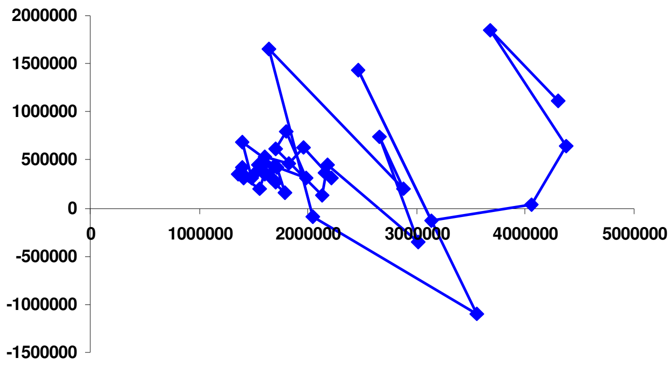

Figure 14: Estimated annual CRA 6 production plotted against estimated biomass, 1970–2008.

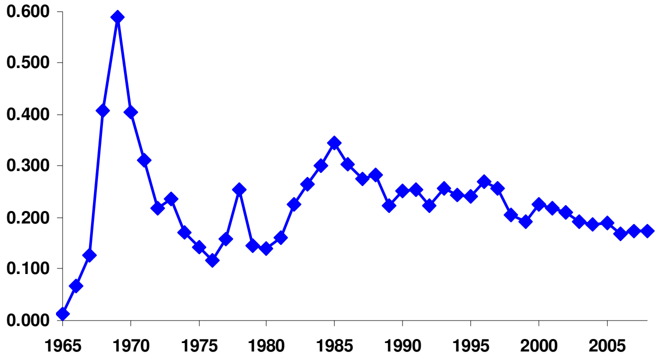

Figure 15: CRA 6 exploitation rate estimated from the simple method described in the text.

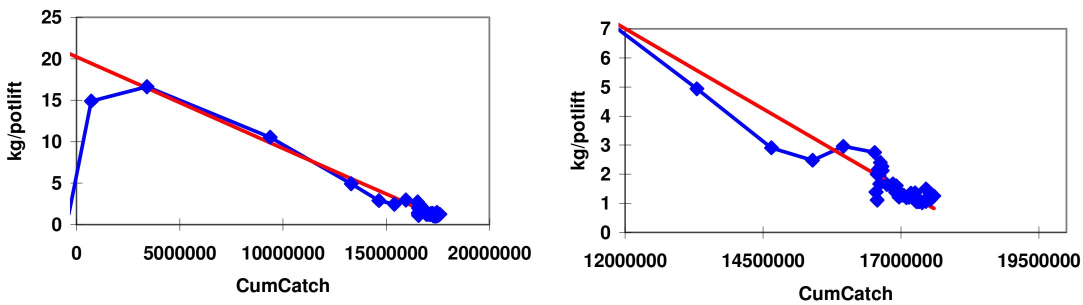

Figure 16: CPUE (kg/pot) (diamonds) plotted against cumulative catch (kg) minus annual production of 388 680 kg for the whole data series (left) and 1970 onwards (right). The straight line is a linear regression.

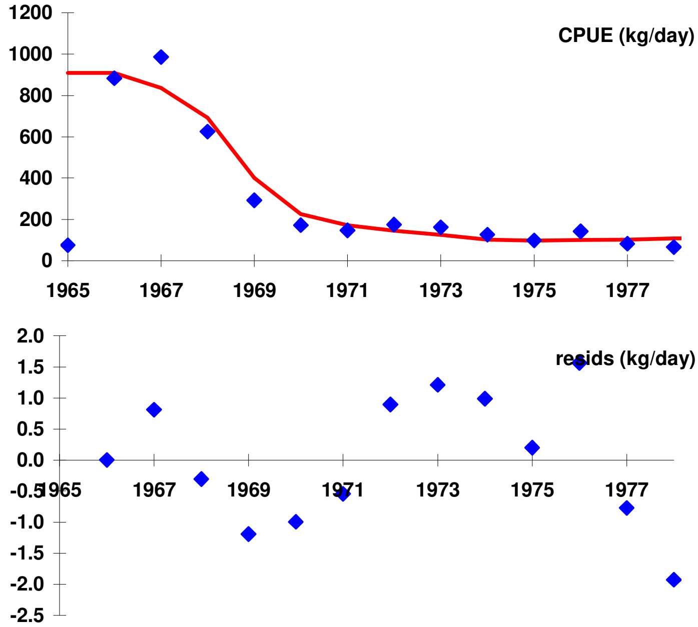

Figure 17: The fit to CPUE in kg/day (upper) from the base case MPD fit with the surplus production model: diamonds are the observed and the line is the predicted CPUE; and residuals from the fit (lower).

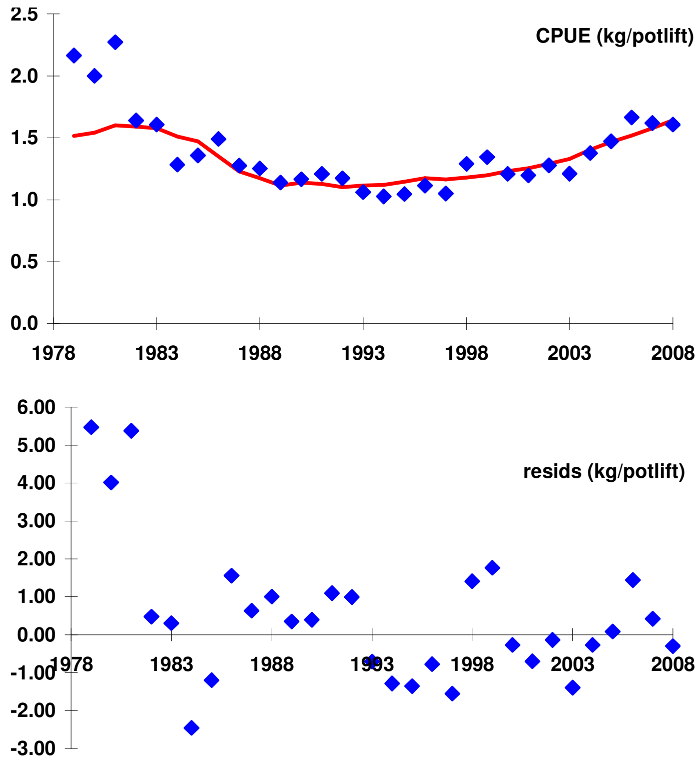

Figure 18: The fit to CPUE in kg/pot (upper) from the base case MPD fit with the surplus production model: diamonds are the observed and the line is the predicted CPUE; and residuals from the fit (lower).

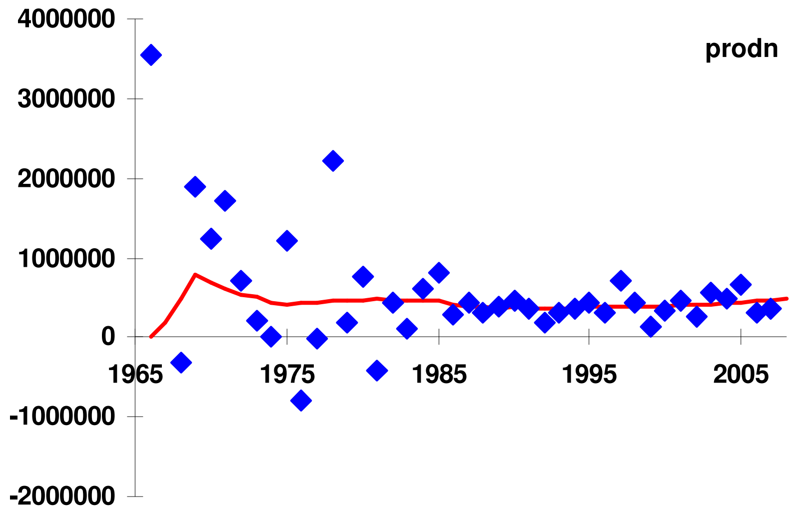

Figure 19: The relation between observed (diamonds) and predicted (line) production trajectories from the base case MPD fit with the surplus production model.

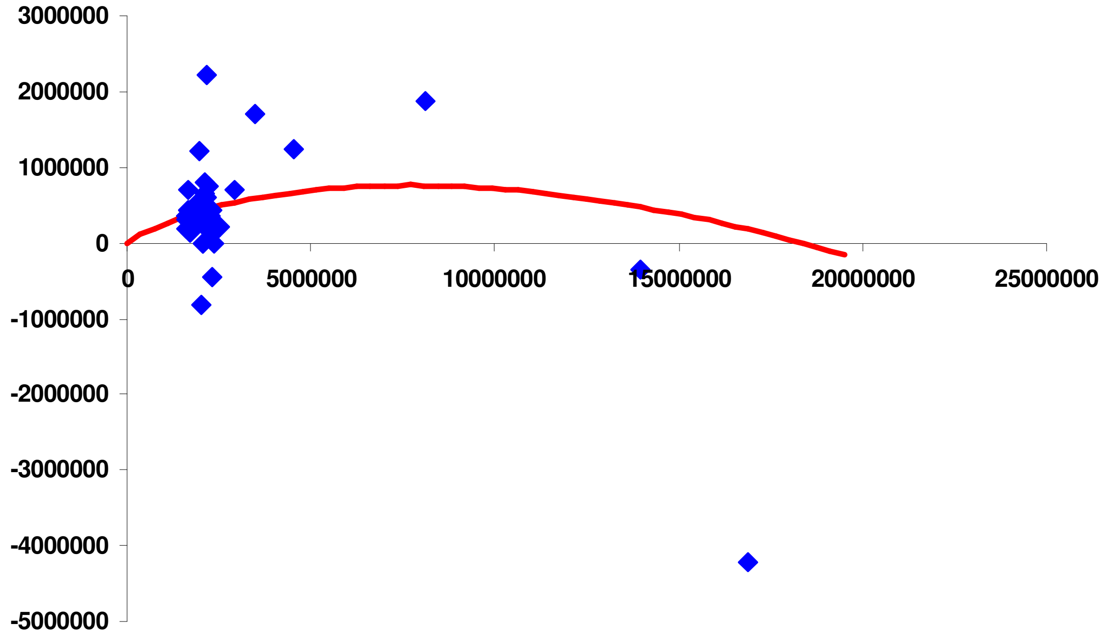

Figure 20: From the base case MPD fit with the surplus production model, comparing observed production (diamonds) and predicted production (line) as functions of biomass.

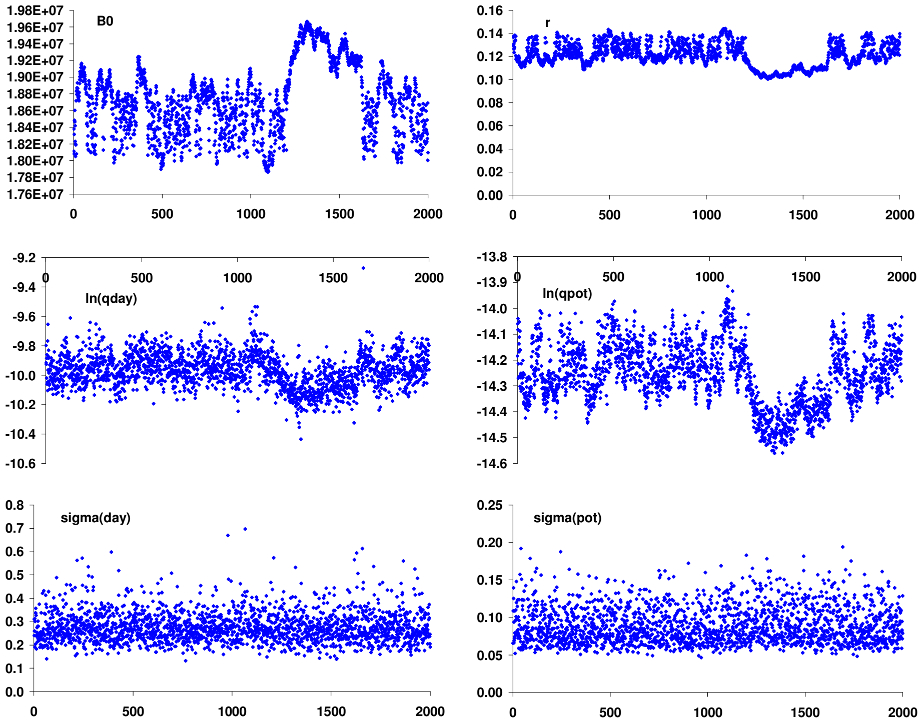

Figure 21: Traces for estimated parameters of the surplus production model from the McMC chain.

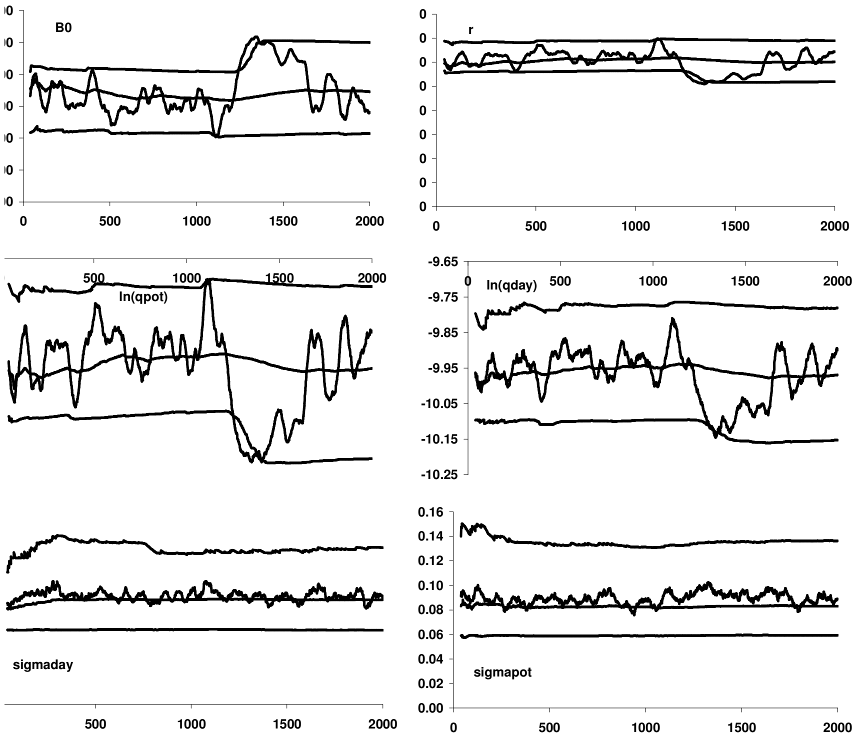

Figure 22: Diagnostic plots for estimated parameters of the surplus production model. The upper line the running 95th quantile; the lower line is the running 5th quantile; the smoother central line is the running median and the jagged central line is a moving mean (over 50 samples). The x-axis is the number of the sample, progressing through the McMC chain, and the y-axis is the parameter value.

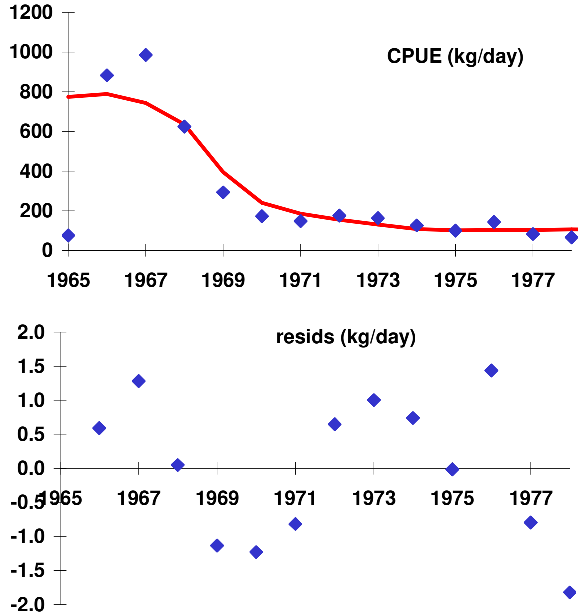

Figure 23: The fit to CPUE in kg/day (upper) from the base case MPD fit with the constant production model: diamonds are the observed and the line is the predicted CPUE; and residuals from the fit (lower).

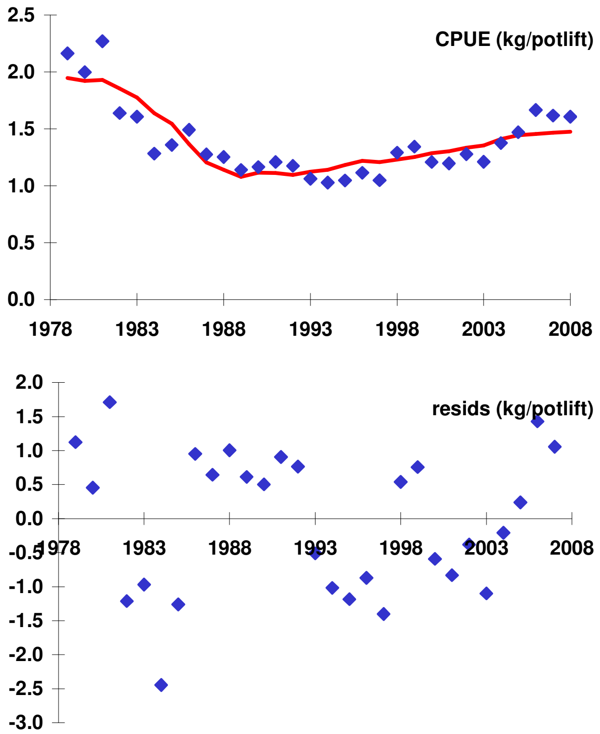

Figure 24: The fit to CPUE in kg/pot (upper) from the base case MPD fit with the constant production model: diamonds are the observed and the line is the predicted CPUE; and residuals from the fit (lower).

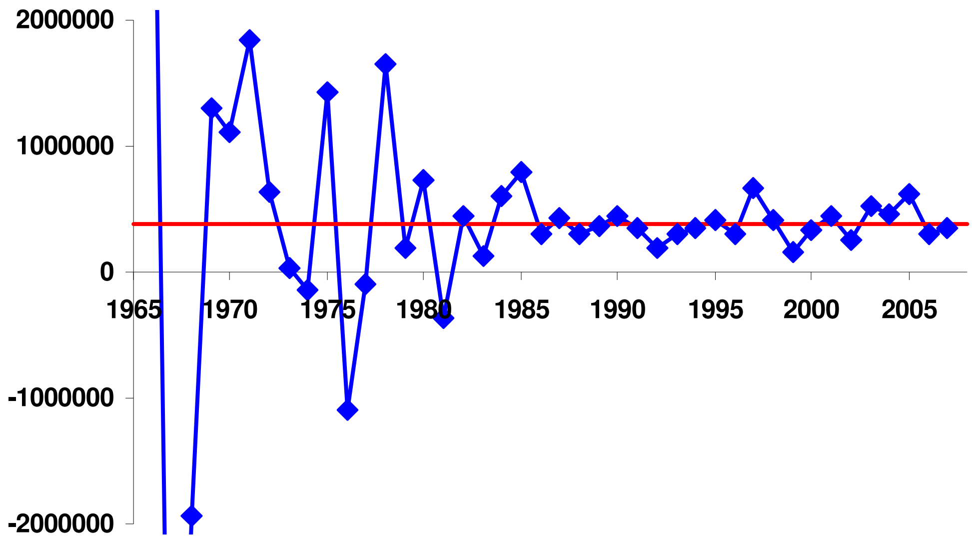

Figure 25: Comparing the base case MPD estimate of constant production (line) with observed production (diamonds). Note that the y-axis scale is truncated to 2 million kg, and that observed production is off this scale for the first three years (see Figure 11).

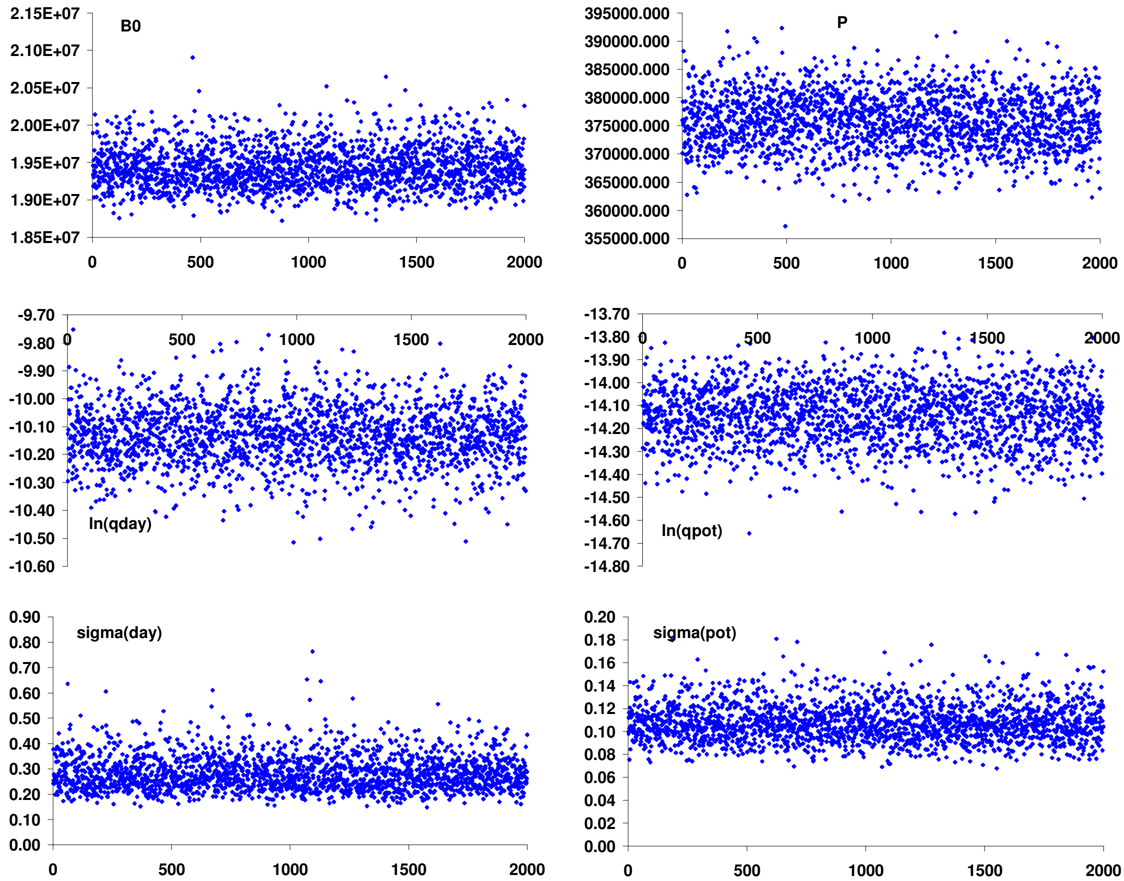

Figure 26: Traces for estimated parameters of the constant production model from the McMC chain.

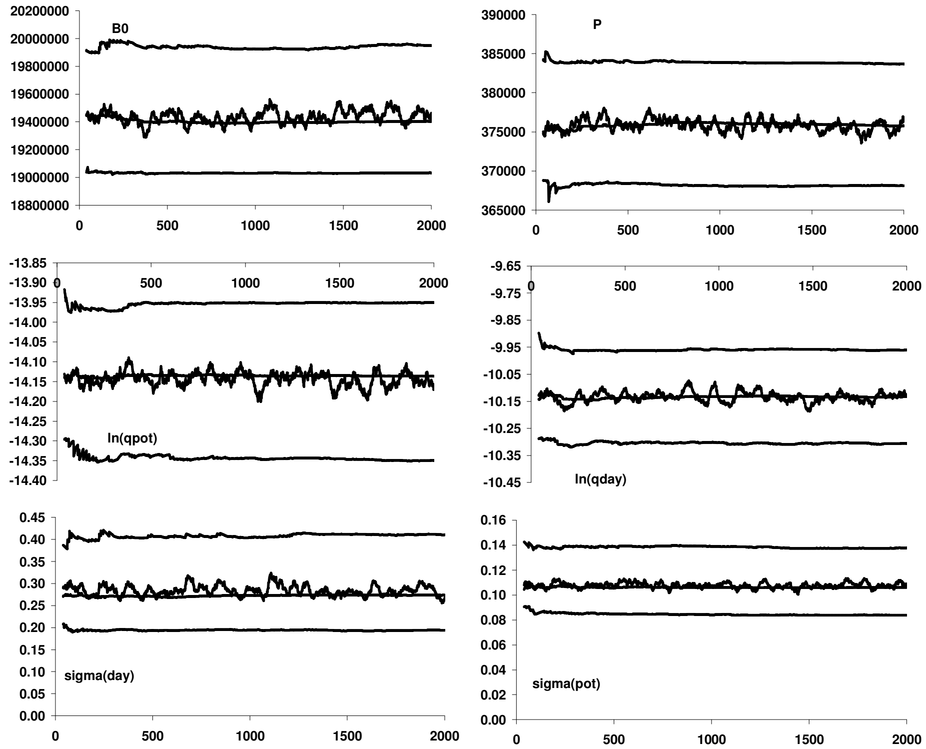

Figure 27: Diagnostic plots for estimated parameters of the constant production model. The upper line the running 95th quantile; the lower line is the running 5th quantile; the smoother central line is the running median and the jagged central line is a moving mean (over 50 samples). The x-axis is the number of the sample, progressing through the McMC chain, and the y-axis is the parameter value.

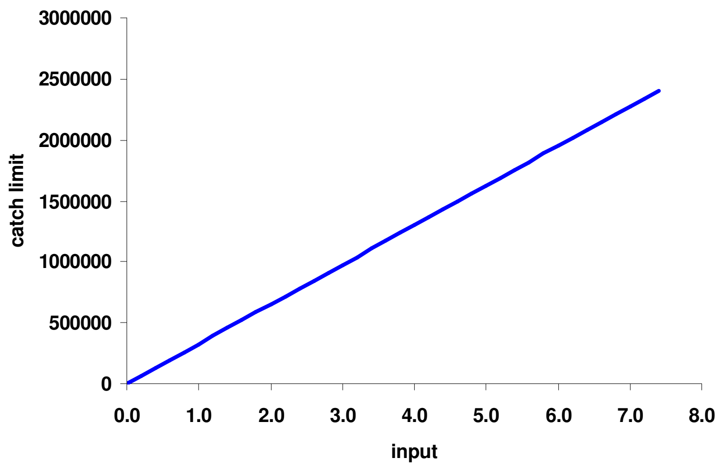

Figure 28: A member of the simplest form of the Rule 4 family. In this member, TACC is 325 000 times CPUE in the previous year.

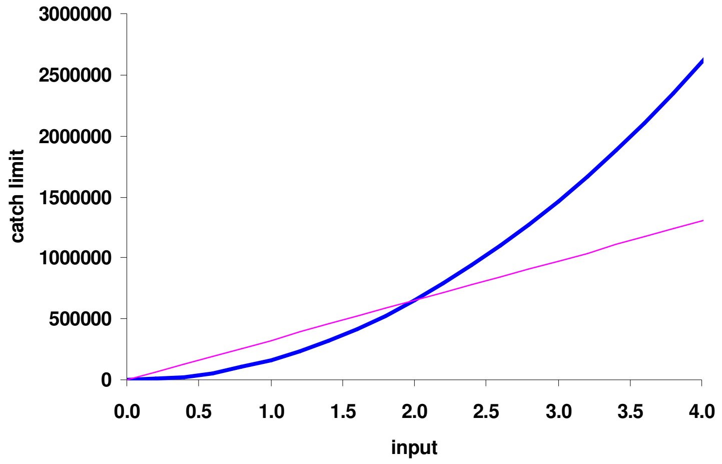

Figure 29: The same rule with a shape parameter of 2. The rule above is shown in the light line: the two rules converge at a CPUE of 2.

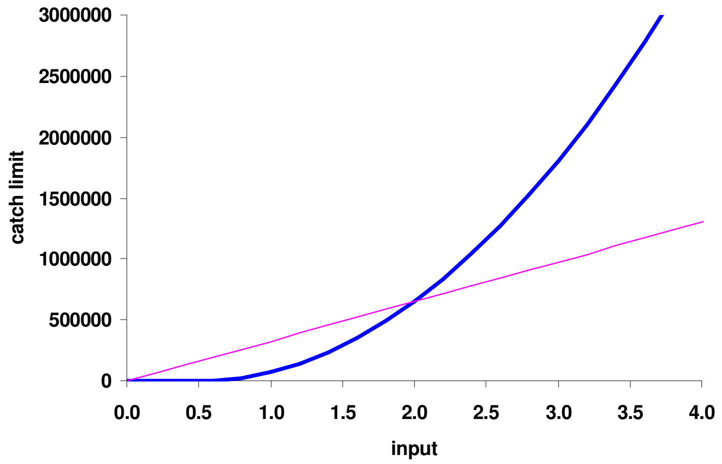

Figure 30: As above, but with a lower CPUE threshold of 0.5 kg/pot. The rule in Figure 28 is shown in the light line: the two rules converge at a CPUE of 2.

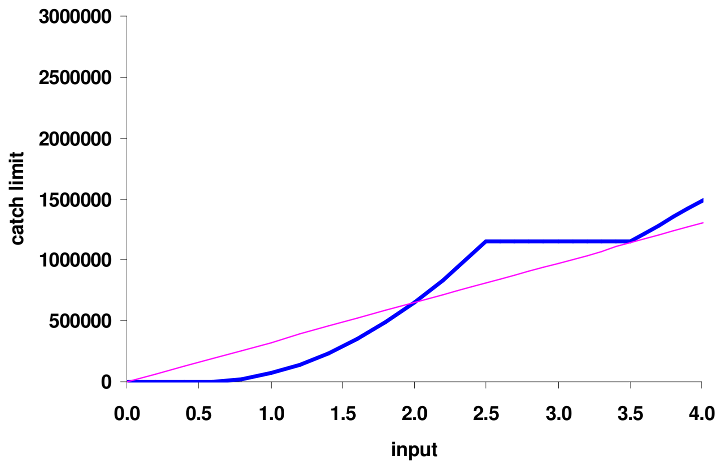

Figure 31: As above, but with a plateau between 2.5 and 3.5 kg/pot. The rule in Figure 28 is shown in the light line: the two rules converge at a CPUE of 2.

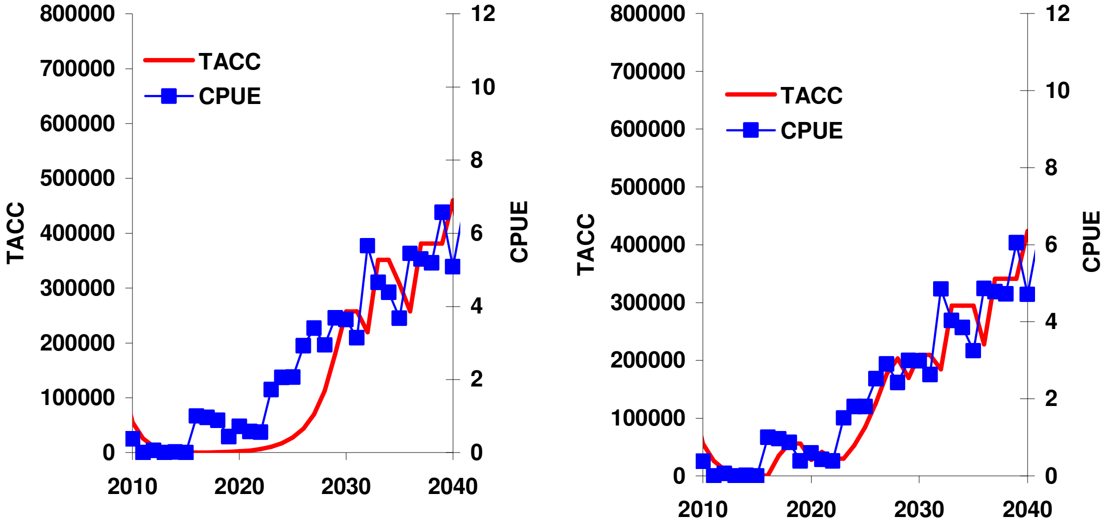

Figure 32: Showing the operation of a harvest control under the constant production model in testing, in a run where the biomass reached a very low value. On the left: with unmodified maximum change procedure; on the right: with modified maximum change procedure.

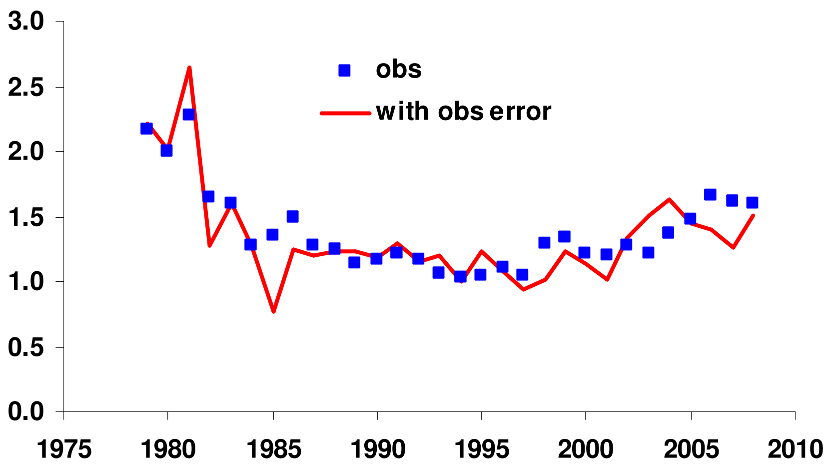

Figure 33: Showing the scale of CPUE observation error with a standard deviation of 0.15.

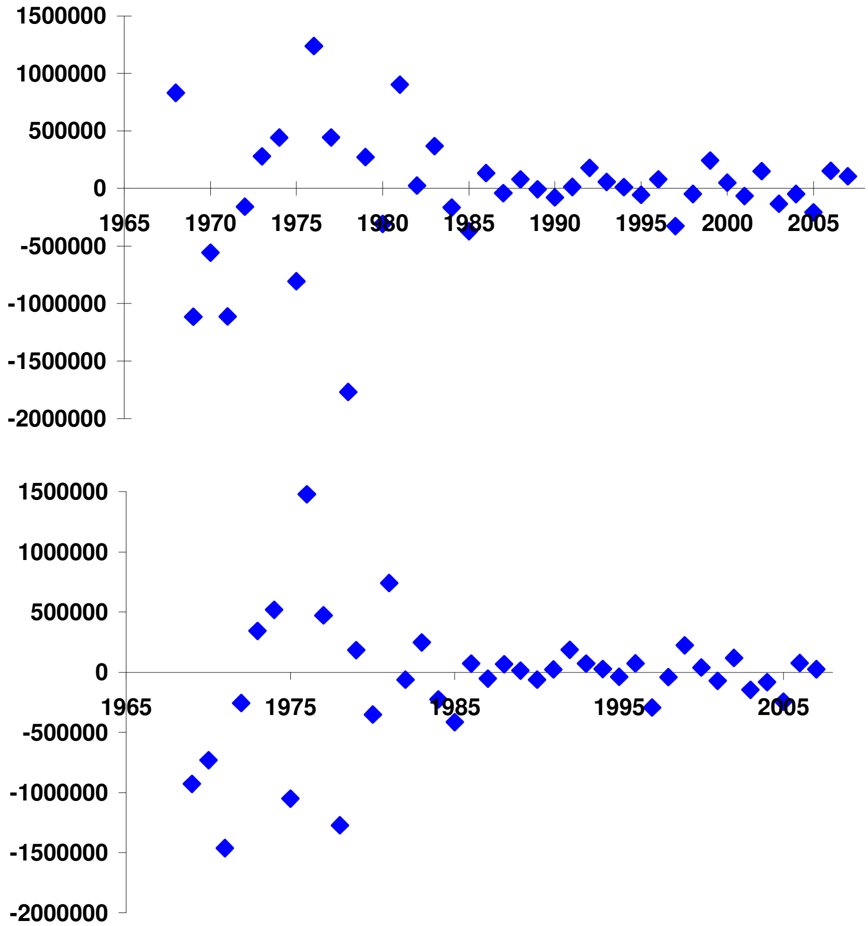

Figure 34: Production deviations from the MPDs of the surplus production (upper) and constant production models.

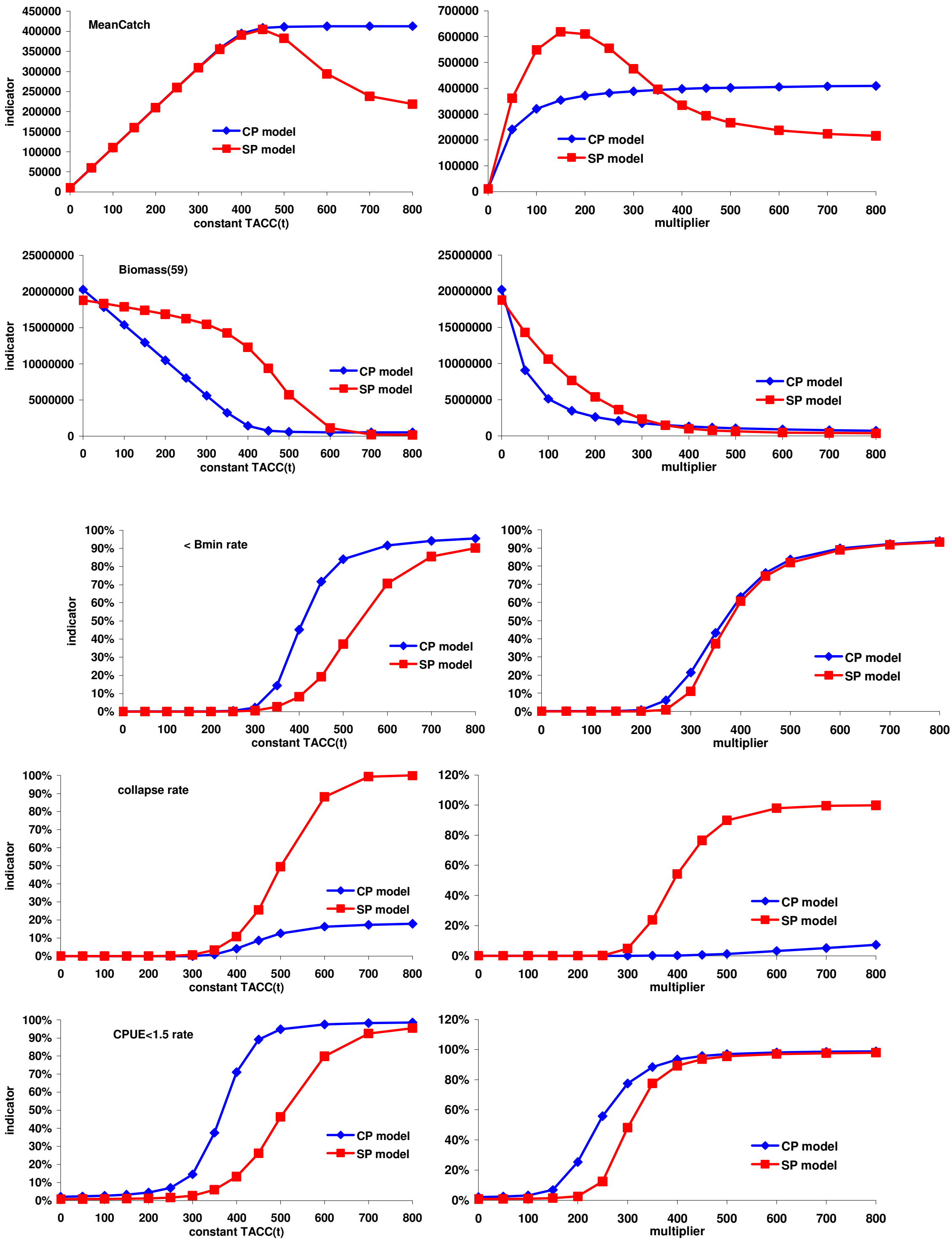

Figure 35: Some indicator summaries from preliminary explorations with the constant production (diamonds) and surplus production (squares) models with constant TACCs (left) and different mulitipliers for a simple Rule 4 (right). Catch and biomass in kg. Rates are the percentage of years (Bmin and low CPUE) or runs (collapse).

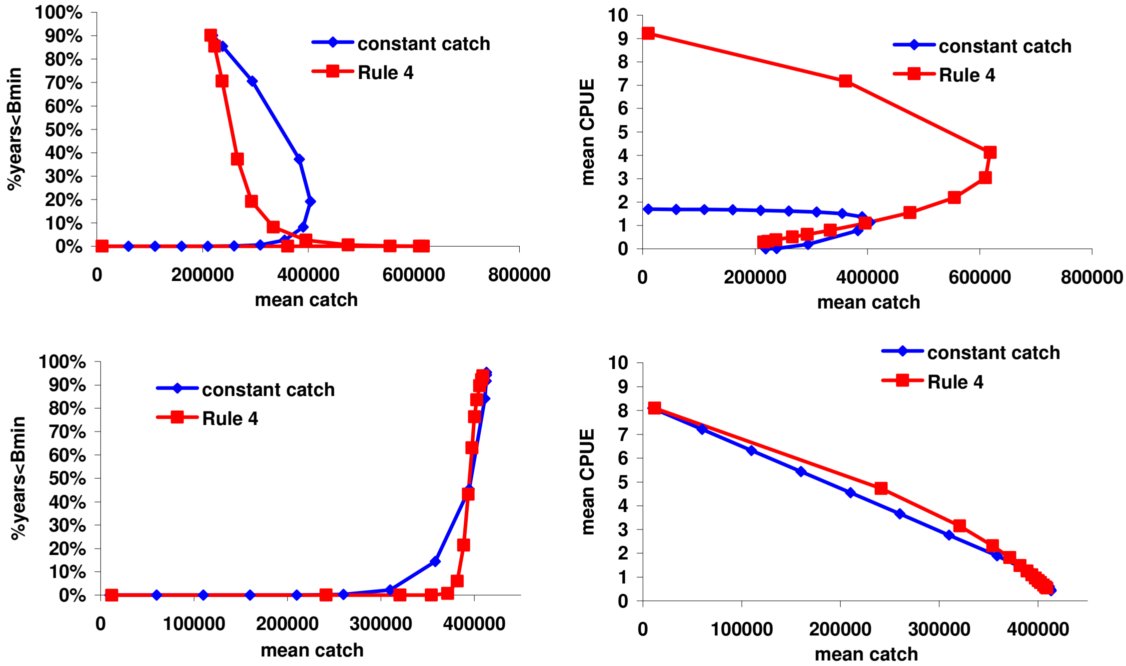

Figure 36: Comparison of two indicators – percentage of years with low CPUE (left) and the mean CPUE (right) from the constant catch (diamonds) and Rule 4 (squares) rules using from the surplus production model (upper) and constant production model (lower).

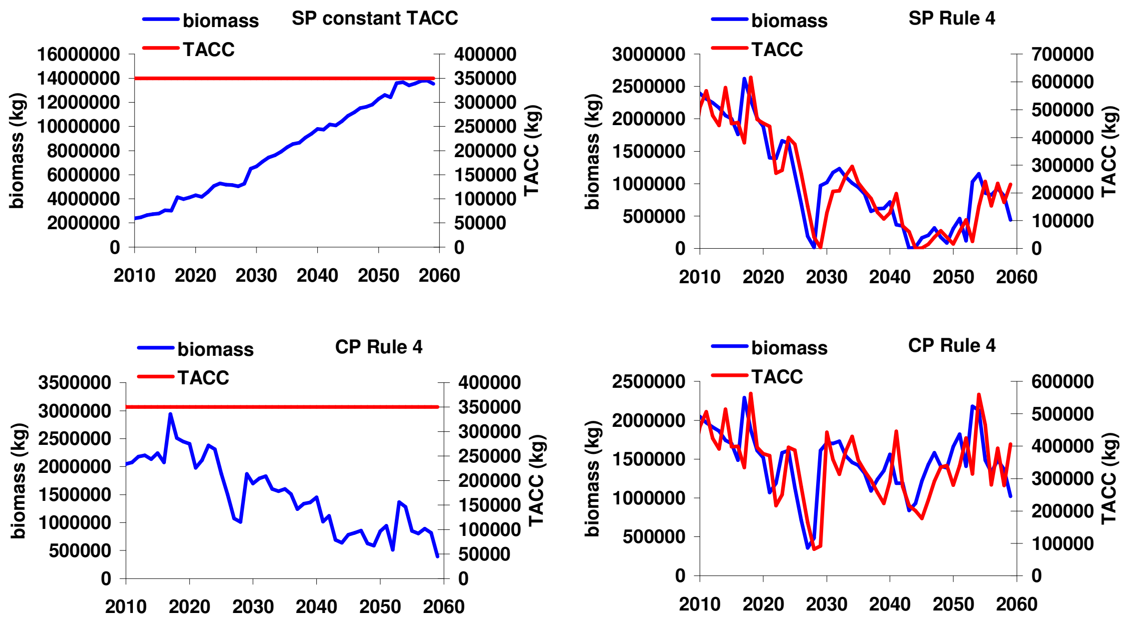

Figure 37: Comparison of run number 430, made with the surplus (top) or constant (bottom) production model, using a constant TACC of 350 t (left) or Rule 4 with a multiplier of 350 t (right).

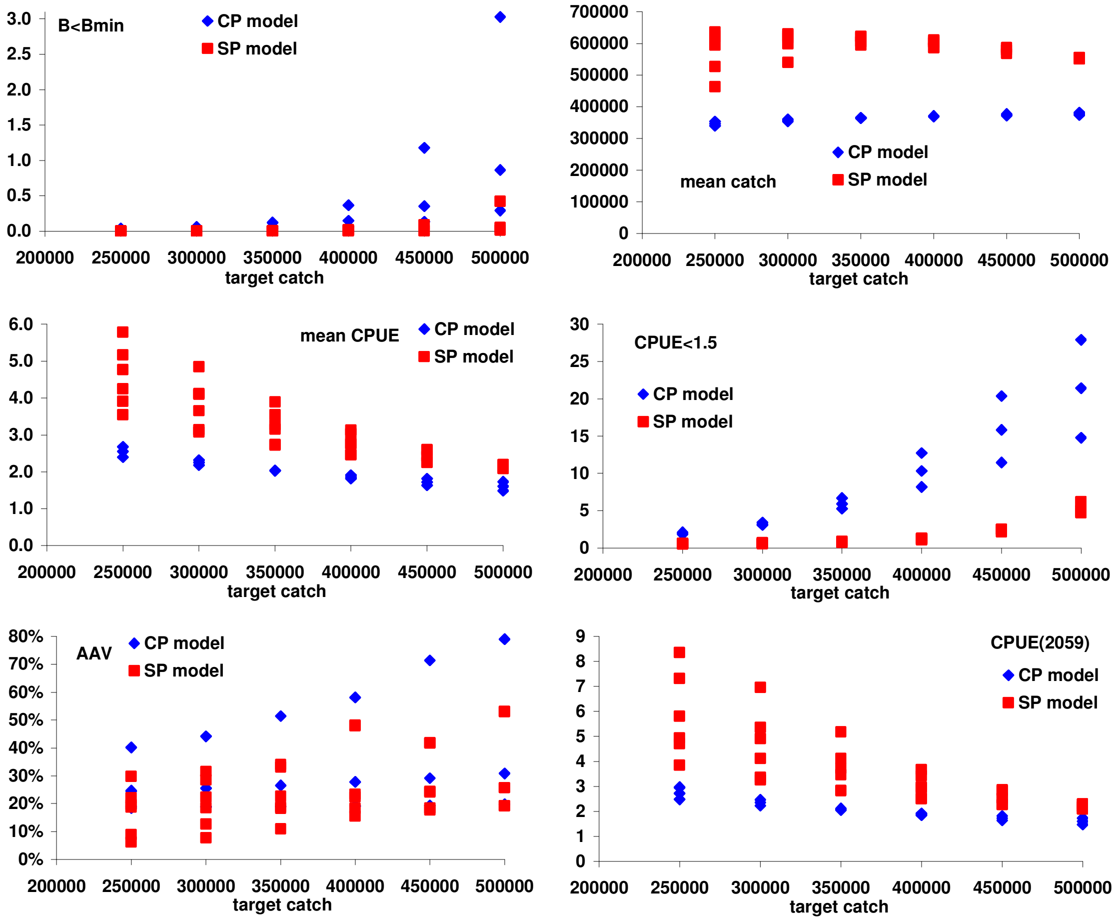

Figure 38: From the intermediate runs with 36 rules, the key indicators shown plotted against target catch (rule parameter 2) for both operating models.

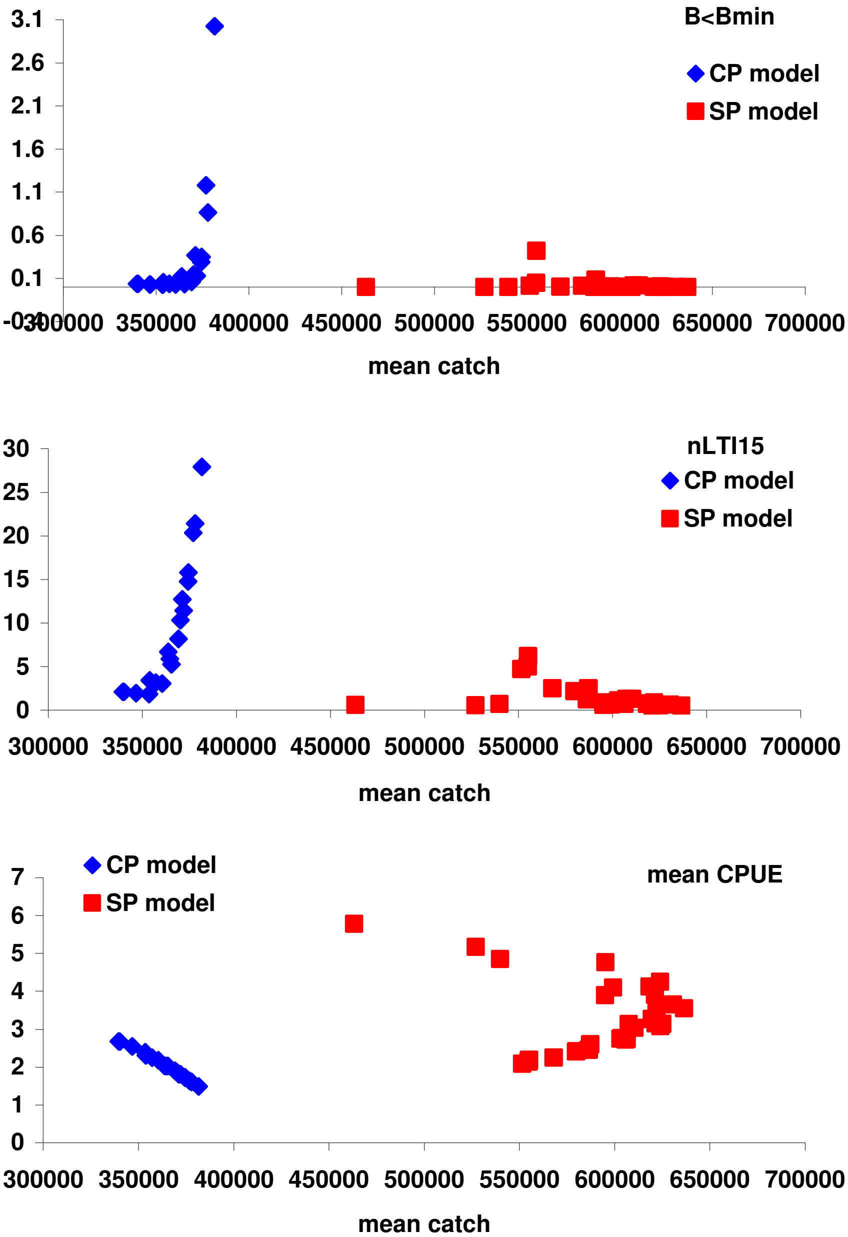

Figure 39: Three key indicators from the intermediate runs with both models, plotted against the mean catch.

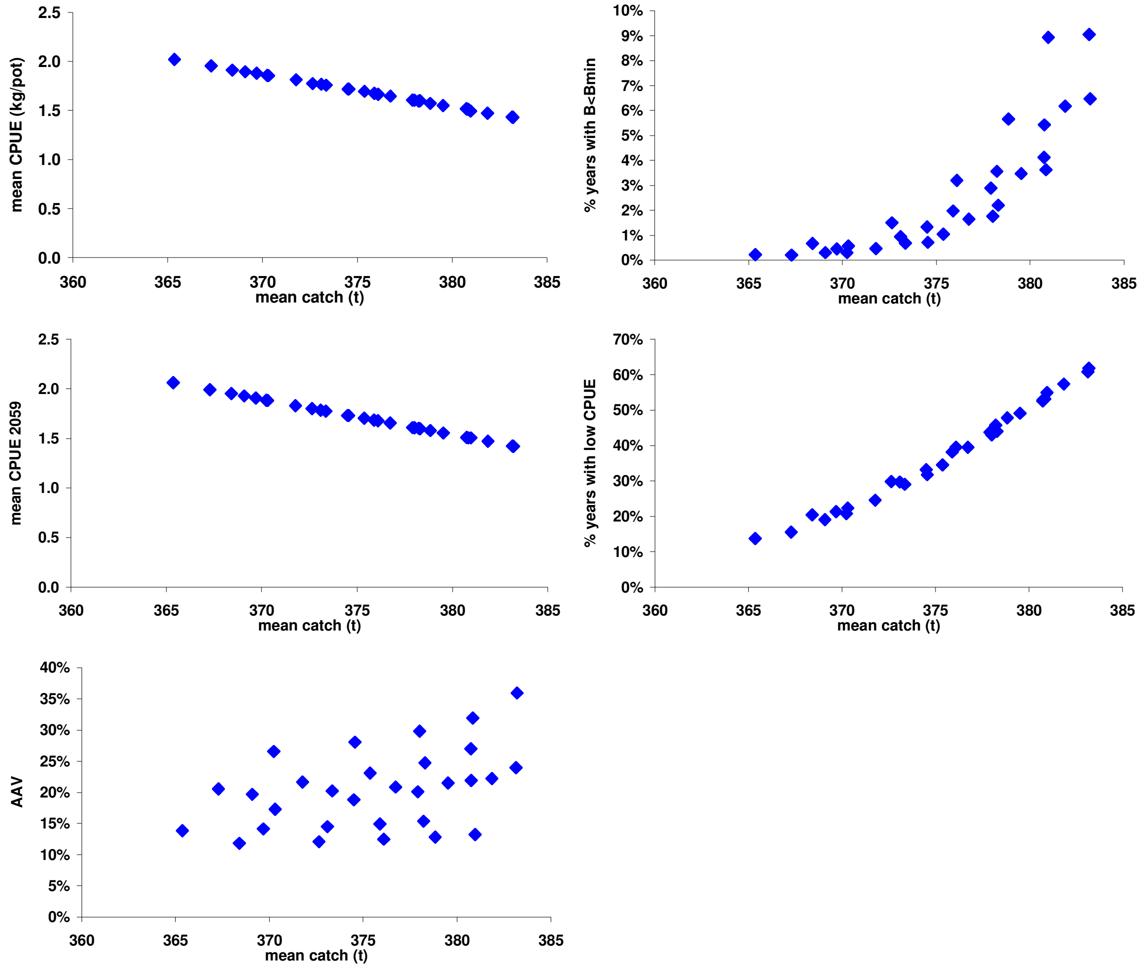

Figure 40: Key indicators plotted against mean catch from the 60 final harvest control rules run under the CP model.