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The 2005 stock assessment of paua (*Haliotis iris*) in PAU 7

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P. A. Breen
S. W. Kim

NIWA
Private Bag 14901
Wellington

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EXECUTIVE SUMMARY

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New Zealand Fishery Assessment Report 2005/47. **114 p.**

A length-based paua stock assessment model was used to assess the PAU 7 stock of paua (abalone) (*Haliotis iris*). The assessment used Bayesian techniques to estimate model parameters, the state of the stock, future states of the stock and their uncertainties. Point estimates from the mode of the joint posterior distribution were used to explore sensitivity of the results to model assumptions and the input data; the assessment itself was based on marginal posterior distributions generated from Markov chain-Monte Carlo simulation.

The model was revised slightly from the 2003 assessment model used for PAU 7 by adding variables for a second CPUE abundance index. The reporting system that provides data used to estimate CPUE changed in 2001, and data from the two systems were used as two sequential, non-overlapping series. A full description of the model is provided.

The model was fitted to seven datasets from areas 17 and 38 within PAU 7: two standardised CPUE series, a standardised index of relative abundance from research diver surveys, proportions-at-length from commercial catch sampling and research diver surveys, tag-recapture data and maturity-at-length data.

Iterative re-weighting of the datasets produced a base case result in which the standard deviations of the normalised residuals were close to unity for most datasets. Model results for PAU 7 suggest a stock that is depleted: current levels of spawning and recruited biomass are well below agreed reference levels from an earlier period in the fishery history. The current exploitation rate is relatively high, at an estimated 60%.

The model projections, made for three years using recruitments re-sampled from the recent model estimates, suggest a very strong likelihood of rebuilding for both spawning and recruited biomass. Risks of decreased biomass are small. The rate of rebuilding will depend on catch, and projections were made, at MFish's request, with a wide range of alternative catch assumptions.

Robustness and uncertainties associated with the assessment are explored and discussed. Data from areas 18 and 36, outside the substock that was assessed, are reviewed.

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1. INTRODUCTION

1.1 Overview

This document presents a Bayesian stock assessment of blackfoot paua (abalone) (*Haliotis iris*) in PAU 7 (at the northern end of the South Island, Figure 1) using data to the end of 2003–04 and some data from the 2004–05 fishing season. The assessment is made with the length-based model first used in 1999 for PAU 5B (Breen et al. 2000a) and revised for subsequent assessments in PAU 5B (Stewart Island) and PAU 7 (Andrew et al. 2000a, Breen et al. 2000b, Breen et al. 2001, Breen & Kim 2003). Model revisions made for PAU 4 (Breen & Kim, 2004a) and PAU 5A (Breen & Kim, 2004b) in 2004 were mostly discarded. The model was published by Breen et al. (2003).

Until recently most catches were taken from statistical areas 17 and 38 (Figure 1). There is no time series of research diver surveys from outside these areas, and proportions-at-length from commercial catch sampling are very different from the other two areas, 18 and 36 (see Section 5). Accordingly, Breen et al. (2001) and Breen & Kim (2003) based their assessments on areas 17 and 38 only. The Shellfish Fishery Assessment Working Group agreed to continue this practice for this assessment.

The model is driven by estimated commercial and non-commercial catches from 1974 through 2005 and is fitted to seven sets of data described below: standardised CPUE from the MFish CELR and PCELR reporting systems (these datasets are termed "CPUE" and "PCPUE" respectively), a standardised research diver survey index (RDSI) described for other areas by Andrew et al. (2000b, 2002), proportion-at-length data from commercial catch sampling (CSLF) and from research diver surveys (RDLF) (Andrew et al. 2000a), maturity data obtained during research diver surveys and a set of growth increment data.

The assessment was made in several steps. First, the model was fitted to the data with arbitrary weights on the various data sets. The weights were then iteratively adjusted to produce balanced residuals among the datasets. The fit obtained is the mode of the joint posterior distribution of parameters (MPD). Next, from the resulting fit, Markov chain-Monte Carlo (McMC) simulations were made to obtain a large set of samples from the joint posterior distribution. From this set of samples, forward projections were made with different assumed catch levels and a set of agreed indicators was obtained. Sensitivity of the results was explored by comparing MPD fits made with datasets removed one at a time and by comparing McMC retrospective analyses.

This document describes the model, datasets, assumptions made in fitting, the fit of the model to the data, projection results and sensitivity trials.

1.2 Description of the fishery

The paua fishery was summarised by Schiel (1992), Annala et al. (2003) and in numerous previous assessment documents (e.g., Schiel 1989, McShane et al. 1994, 1996, Breen et al. 2000a, 2000b, 2001, Breen & Kim 2003, Breen & Kim 2004a, 2004b). A further summary is not presented here.

The fishing year for paua is from 1 October to 30 September. In what follows we refer to fishing year by the second portion; thus we call the 1997–98 fishing year "1998".

2. MODEL

This section describes the model used for stock assessment of PAU 7 in 2005. The model was developed for use in PAU 5B in 1999 and has been revised each year for subsequent assessments, in many cases echoing changes made to the rock lobster assessment model (Breen et al. 2002; Kim et al. 2004), which is a similar but more complex length-based Bayesian model. Only minor changes for maintenance were made in 2005 to the 2003 assessment model (Breen & Kim 2003).

2.1 Changes to the 2003 assessment model

Revised equations are provided where the model is described fully below. Only one substantial change was made. Minor changes included correcting the production calculation and reading projected catch in as a vector rather than a scalar.

2.1.1 New abundance index

Previous assessments fitted the model to a single abundance index derived from CPUE data. However, the reporting system changed in 2001 from the older Catch and Effort Landing Returns (CELRs) to the Paua Catch and Effort Landing Returns (PCELRs). This change involves much finer area reporting and some additional information such as diving conditions. The new data allow estimation of a four-year series that can be treated as a different series from that derived from the older data.

Accordingly, the model was revised to include this second series, which we called PCPUE.

2.2 Model description

The model (BLePSAM: Bayesian Length-based Paua Stock Assessment Model) does not use age; instead it uses a number of length bins (51 in this assessment), each of 2 mm shell length. The left-hand edge of the first bin is 70 mm and the largest bin is well above the maximum size observed. Sexes are not distinguished. The time step is one year for the main dynamics. There is no spatial structure within the area modelled. The model is implemented in AD Model Builder™ (Otter Research Ltd., http://otter-rsch.com/admodel.htm) version 6.2.1, compiled with the Borland 5.01 compiler.

2.2.1 Estimated parameters

Parameters estimated by the model are as follows. The parameter vector is referred to collectively as θ.

$\ln(R0)$	natural logarithm of base recruitment
M	instantaneous rate of natural mortality
g_α	expected annual growth increment at length α
g_β	expected annual growth increment at length β
ϕ	c.v. of the expected growth increment
q^I	scalar between recruited biomass and CPUE
X	coefficient of proportionality between q^I and q^{I2}, the scalar for PCPUE
q^J	scalar between numbers and the RDSI
L_{50}	length at which maturity is 50%

L_{95-50}	interval between L_{50} and L_{95}
T_{50}	length at which research diver selectivity is 50%
T_{95-50}	distance between T_{50} and T_{95}
D_{50}	length at which commercial diver selectivity is 50%
D_{95-50}	distance between D_{50} and D_{95}
$\widetilde{\sigma}$	common component of error
h	shape of CPUE *vs.* biomass relation
ε	vector of annual recruitment deviations, estimated from 1977 to 2004

2.2.2 Constants

l_k	length of an abalone at the midpoint of the *k*th length class (l_k for class 1 is 71 mm, for class 2 is 73 mm and so on)
σ_{MIN}	minimum standard deviation of the expected growth increment (assumed to be 1 mm)
σ_{obs}	standard deviation of the observation error around the growth increment (assumed to be 0.25 mm)
MLS_t	minimum legal size in year *t* (assumed to be 125 mm for all years)
$P_{k,t}$	a switch based whether abalone in the *k*th length class in year *t* are above the minimum legal size (MLS) ($P_{k,t} = 1$) or below ($P_{k,t} = 0$)
a,b	constants for the length-weight relation, taken from Schiel & Breen (1991) (2.592E-08 and 3.322 respectively, giving weight in kg)
w_k	the weight of an abalone at length l_k
ϖ^I	relative weight assigned to the CPUE dataset. This and the following relative weights were varied between runs to find a basecase with balanced residuals
ϖ^{I2}	relative weight assigned to the PCPUE dataset.
ϖ^J	relative weight assigned to the RDSI dataset
ϖ^r	relative weight assigned to RDLF dataset
ϖ^s	relative weight assigned to CSLF dataset
ϖ^{mat}	relative weight assigned to maturity-at-length data
κ_t^s	normalised square root of the number measured greater than 113 mm in CSLF records for each year, normalised by the lowest year
κ_t^r	normalised square root of the number measured greater than 89 mm in RDLF records for each year, normalised by the lowest year
$U^{\max}$	exploitation rate above which a limiting function was invoked (0.80 for the base case)
μ_M	mean of the prior distribution for *M*, based on a literature review by Shepherd & Breen (1992)
σ_M	assumed standard deviation of the prior distribution for *M*
σ_ε	assumed standard deviation of recruitment deviations in log space (part of the prior for recruitment deviations)

n_ε	number of recruitment deviations
α	length associated with g_α (75 mm)
β	length associated with g_β (120 mm)

2.2.3 Observations

C_t	observed catch in year *t*
I_t	standardised CPUE in year *t*
$I2_t$	standardised PCPUE in year *t*
σ_t^I	standard deviation of the estimate of observed CPUE in year *t*, obtained from the standardisation model
σ_t^{I2}	standard deviation of the estimate of observed PCPUE in year *t*, obtained from the standardisation model
J_t	standardised RDSI in year *t*
σ_t^J	the standard deviation of the estimate of RDSI in year t, obtained from the standardisation model
$p_{k,t}^r$	observed proportion in the *k*th length class in year *t* in RDLF
$p_{k,t}^s$	observed proportion in the *k*th length class in year *t* in CSLF
l_j	initial length for the *j*th tag-recapture record
d_j	observed length increment of the *j*th tag-recapture record
Δt_j	time at liberty for the *j*th tag-recapture record
p_k^{mat}	observed proportion mature in the *k*th length class in the maturity dataset

2.2.4 Derived variables

$R0$	base number of annual recruits
$N_{k,t}$	number of abalone in the *k*th length class at the start of year *t*
$N_{k,t+0.5}$	number of abalone in the *k*th length class in the mid-season of year *t*
$R_{k,t}$	recruits to the model in the *k*th length class in year *t*
g_k	expected annual growth increment for abalone in the *k*th length class
σ^{g_k}	standard deviation of the expected growth increment for abalone in the *k*th length class, used in calculating $\mathbf{G}$
$\mathbf{G}$	growth transition matrix
B_t	biomass of abalone available to the commercial fishery at the beginning of year *t*
$B_{t+0.5}$	biomass of abalone above the MLS in the mid-season of year *t*
$S_{t+0.5}$	biomass of mature abalone in the mid-season of year *t*
U_t	exploitation rate in year *t*
A_t	the complement of exploitation rate
$SF_{k,t}$	finite rate of survival from fishing for abalone in the *k*th length class in year *t*

V_k^r	relative selectivity of research divers for abalone in the *k*th length class
V_k^s	relative selectivity of commercial divers for abalone in the *k*th length class
$\sigma_{k,t}^r$	error of the predicted proportion in the *k*th length class in year *t* in RDLF data
$\sigma_{k,t}^s$	error of the predicted proportion in the *k*th length class in year *t* in CSLF data
σ_j^d	standard deviation of the predicted length increment for the *j*th tag-recapture record
σ_j^{tag}	total error predicted for the *j*th tag-recapture record
σ_k^{mat}	error of the proportion mature-at-length for the *k*th length class
$-\ln(\mathrm{L})$	negative log-likelihood
f	total function value

2.2.5 Predictions

$\hat{I}_t$	predicted CPUE in year *t*
$\hat{I}2_t$	predicted PCPUE in year *t*
$\hat{J}_t$	predicted RDSI in year *t*
$\hat{p}_{k,t}^r$	predicted proportion in the *k*th length class in year *t* in research diver surveys
$\hat{p}_{k,t}^s$	predicted proportion in the *k*th length class in year *t* in commercial catch sampling
$\hat{d}_j$	predicted length increment of the *j*th tag-recapture record
$\hat{p}_k^{mat}$	predicted proportion mature in the *k*th length class

2.2.6 Initial conditions

The initial population is assumed to be in equilibrium with zero fishing mortality and the base recruitment. The model is run for 60 years with no fishing to obtain near-equilibrium in numbers-at-length. Recruitment is evenly divided among the first five length bins:

$$R_{k,t} = 0.2R0 \qquad \text{for } 1 \le k \le 5 \tag{1}$$

$$R_{k,t} = 0 \qquad \text{for } k > 5 \tag{2}$$

A growth transition matrix is calculated inside the model from the estimated growth parameters. If the growth model is linear, the expected annual growth increment for the *k*th length class is

$$\Delta l_k = \left(\frac{\beta g_\alpha - \alpha g_\beta}{g_\alpha - g_\beta} - l_k\right)\left[1-\left(1+\frac{g_\alpha - g_\beta}{\alpha - \beta}\right)\right] \tag{3}$$

The model uses the AD Model Builder™ function *posfun*, with a dummy penalty, to ensure a positive expected increment at all lengths, using a smooth differentiable function. The *posfun* function is also used with a real penalty to force the quantity $\left(1+\frac{g_\alpha - g_\beta}{\alpha - \beta}\right)$ to remain positive.

If the growth model is exponential (used for the base case), the expected annual growth increment for the *k*th length class is

$$(4) \qquad \Delta l_k = g_\alpha \left(g_\beta / g_\alpha \right)^{(l_k - \alpha)/(\beta - \alpha)}$$

again using *posfun* with a dummy penalty to ensure a positive expected increment at all lengths.

The standard deviation of g_k is assumed to be proportional to g_k with minimum σ_{MIN}:

$$(5) \qquad \sigma^{g_k} = \left(g_k \phi - \sigma_{MIN} \right) \left(\frac{1}{\pi} \tan^{-1} \left(10^6 \left(g_k \phi - \sigma_{MIN} \right) \right) + 0.5 \right) + \sigma_{MIN}$$

From the expected increment and standard deviation for each length class, the probability distribution of growth increments for an abalone of length l_k is calculated from the normal distribution and translated into the vector of probabilities of transition from the *k*th length bin to other length bins to form the growth transition matrix **G**. Zero and negative growth increments are permitted, i.e. the probability of staying in the same bin or moving to a smaller bin can be non-zero.

In the initialisation, the vector $\mathbf{N}_t$ of numbers-at-length is determined from numbers in the previous year, survival from natural mortality, the growth transition matrix **G** and the vector of recruitment $\mathbf{R}_t$:

$$(6) \qquad \mathbf{N}_t = \left(\mathbf{N}_{t-1} e^{-M} \right) \bullet \mathbf{G} + \mathbf{R}_t$$

where the dot (•) denotes matrix multiplication.

2.2.7 Dynamics

2.2.7.1 Sequence of operations

After initialising, the first model year is 1965 and the model is run through 2005. In the first 9 years the model is run with an assumed catch vector, because it is unrealistic to assume that the fishery was in a virgin state when the first catch data became available in 1974. The assumed catch vector rises linearly from zero to the 1974 catch. These years can be thought of as an additional part of the initialisation, but they use the dynamics described in this section.

Model dynamics are sequenced as follows:

- numbers at the beginning of year *t*-1 are subjected to fishing, then natural mortality, then growth to produce the numbers at the beginning of year *t*.
- recruitment is added to the numbers at the beginning of year *t*.
- biomass available to the fishery is calculated and, with catch, is used to calculate the exploitation rate, which is constrained if necessary.
- half the exploitation rate (but no natural mortality) is applied to obtain mid-season numbers, from which the predicted abundance indices and proportions-at-length are calculated. Mid-season numbers are not used further.

2.2.7.2 Main dynamics

For each year t, the model calculates the start-of-the-year biomass available to the commercial fishery. Biomass available to the commercial fishery is:

$$(7) \qquad B_t = \sum_k N_{k,t} V_k^s w_k.$$

where

$$(8) \qquad V_k^s = \frac{1}{1+19^{-\left(\left(l_k - D_{50}\right)/D_{95-50}\right)}}$$

The observed catch is then used to calculate exploitation rate, constrained for all values above U^{max} with the *posfun* function of AD Model Builder™. If the ratio of catch to available biomass exceeds U^{max}, then exploitation rate is constrained and a penalty is added to the total negative log-likelihood function. Let minimum survival rate A_{min} be $1\text{-}U^{max}$ and survival rate A_t be $1\text{-}U_t$:

$$(9) \qquad A_t = 1 - \frac{C_t}{B_t} \qquad\qquad \text{for } \frac{C_t}{B_t} \le U^{\max}$$

$$(10) \qquad A_t = 0.5 A_{\min}\left[1 + \left(3 - \frac{2\left(1 - \frac{C_t}{B_t}\right)}{A_{\min}}\right)^{-1}\right] \qquad \text{for } \frac{C_t}{B_t} > U^{\max}$$

The penalty invoked when the exploitation rate exceeds U^{max} is:

$$(11) \qquad 1000000\left(A_{\min} - \left(1 - \frac{C_t}{B_t}\right)\right)^2$$

This prevents the model from exploring parameter combinations that give unrealistically high exploitation rates. Survival from fishing is calculated as:

$$(12) \qquad SF_{k,t} = 1 - \left(1 - A_t\right) P_{k,t}$$

or

$$(13) \qquad SF_{k,t} = 1 - \left(1 - A_t\right) V_k^s$$

The vector of numbers-at-length in year t is calculated from numbers in the previous year:

$$(14) \qquad \mathbf{N}_t = \left(\left(\mathbf{SF}_{t\text{-}1} \otimes \mathbf{N}_{t\text{-}1}\right) e^{-M}\right) \bullet \mathbf{G} + \mathbf{R}_t$$

where $\otimes$ denotes the element-by-element vector product. The vector of recruitment, $\mathbf{R}_t$ is determined from $R0$ and the estimated recruitment deviations:

$$(15) \qquad R_{k,t} = 0.2 R0 e^{\left(\varepsilon_t - 0.5\sigma_\varepsilon^2\right)} \qquad\qquad \text{for } 1 \le k \le 5$$

$$(16) \qquad R_{k,t} = 0 \qquad\qquad \text{for } k > 5$$

The recruitment deviation parameters ε_t were estimated for all years from 1977; there was no constraint for deviations to have a mean of 1 in arithmetic space except for the constraint of the prior, which had a mean of zero in log space; and we assumed no stock recruitment relationship.

2.2.8 Model predictions

The model predicts CPUE in year *t* from mid-season recruited biomass, the scaling coefficient and the shape parameter:

$$(17) \qquad \hat{I}_t = q^I \left(B_{t+0.5}\right)^h$$

Available biomass $B_{t+0.5}$ is the mid-season vulnerable biomass after half the catch has been removed (no natural mortality is applied, because the time over which half the catch is removed might be short). It is calculated as in equation (7), but using the mid-year numbers, $N_{k,t+0.5}$:

$$(18) \qquad N^{vuln}_{k,t+0.5} = N_{k,t}\left(1 - \frac{\left(1-A_t\right)}{2} V^s_k\right).$$

Similarly,

$$(19) \qquad \hat{I}2_t = q^{I2}\left(B_{t+0.5}\right)^h = Xq^I\left(B_{t+0.5}\right)^h$$

The same shape parameter *h* is used for both series: experiment outside the model showed that this was appropriate despite the different units of measurement for the two series. The predicted research diver survey index is calculated from mid-season model numbers in bins greater than 89 mm length, taking into account research diver selectivity-at-length:

$$(20) \qquad N^{res}_{k,t+0.5} = N_{k,t}\left(1 - \frac{\left(1-A_t\right)}{2} V^r_k\right)$$

$$(21) \qquad \hat{J}_t = q^J \sum_{k=11}^{55} N^{res}_{k,t+0.5}$$

where the scalar is estimated and the research diver selectivity V^r_k is calculated from:

$$(22) \qquad V^r_k = \frac{1}{1 + 19^{-\left(\left(l_k - T_{50}\right)/T_{95-50}\right)}}$$

The model predicts proportions-at-length for the RDLF from numbers in each length class for lengths greater than 89 mm:

$$(23) \qquad \hat{p}^r_{k,t} = \frac{N^{res}_{k,t+0.5}}{\sum_{k=11}^{51} N^{res}_{k,t+0.5}} \qquad \text{for } 11 \le k < 51$$

Predicted proportions-at-length for CSLF are similar:

$$(24) \qquad \hat{p}^{s}_{k,t} = \frac{N^{vuln}_{k,t+0.5}}{\sum_{k=23}^{51} N^{vuln}_{k,t+0.5}} \qquad \text{for } 23 \le k < 51$$

The predicted increment for the *j*th tag-recapture record, using the linear model, is

$$(25) \qquad \hat{d}_j = \left(\frac{\beta g_\alpha - \alpha g_\beta}{g_\alpha - g_\beta} - L_j \right) \left[1 - \left(1 + \frac{g_\alpha - g_\beta}{\alpha - \beta} \right)^{\Delta t_j} \right]$$

where Δt_j is in years. For the exponential model (used in the base case) the expected increment is

$$(26) \qquad \hat{d}_j = \Delta t_j g_\alpha \left(g_\beta / g_\alpha \right)^{(L_j - \alpha)/(\beta - \alpha)}$$

The error around an expected increment is

$$(27) \qquad \sigma_j^{d} = \left(\hat{d}_j \phi - \sigma_{MIN} \right) \left(\frac{1}{\pi} \tan^{-1} \left(10^6 \left(\hat{d}_j \phi - \sigma_{MIN} \right) \right) + 0.5 \right) + \sigma_{MIN}$$

Predicted maturity-at-length is

$$(28) \qquad \hat{p}_k^{mat} = \frac{1}{1 + 19^{-\left((l_k - L_{50}) / L_{95-50} \right)}}$$

2.2.9 Fitting

2.2.9.1 Likelihoods

The distribution of CPUE is assumed to be normal-log and the negative log-likelihood is:

$$(29) \qquad -\ln(\mathbf{L}) \left(\hat{I}_t \mid \theta \right) = \frac{\left(\ln(I_t) - \ln(\hat{I}_t) \right)^2}{2 \left(\sigma_t^I \tilde{\sigma} / \varpi^I \right)^2} + \ln \left(\sigma_t^I \tilde{\sigma} / \varpi^I \right) + 0.5 \ln(2\pi)$$

and similarly for PCPUE:

$$(30) \qquad -\ln(\mathbf{L}) \left(\hat{I2}_t \mid \theta \right) = \frac{\left(\ln(I2_t) - \ln(\hat{I2}_t) \right)^2}{2 \left(\sigma_t^{I2} \tilde{\sigma} / \varpi^{I2} \right)^2} + \ln \left(\sigma_t^{I2} \tilde{\sigma} / \varpi^{I2} \right) + 0.5 \ln(2\pi)$$

The distribution of the RDSI is also assumed to be normal-log and the negative log-likelihood is:

(31) $$-\ln(\mathbf{L})\left(\hat{J}_t \mid \theta\right) = \frac{\left(\ln(J_t) - \ln\left(\hat{J}_t\right)\right)^2}{2\left(\sigma_t^J \tilde{\sigma} \big/ \varpi^J\right)^2} + \ln\left(\sigma_t^J \tilde{\sigma} \big/ \varpi^J\right) + 0.5\ln(2\pi)$$

The proportions-at-length from CSLF data are assumed to be normally distributed, with a standard deviation that depends on the proportion, the number measured and the weight assigned to the data:

(32) $$\sigma_{k,t}^s = \frac{\tilde{\sigma}}{\kappa_t^s \varpi^s \sqrt{p_{k,t}^s + 0.1}}$$

The negative log-likelihood is:

(33) $$-\ln(\mathbf{L})\left(\hat{p}_{k,t}^s \mid \theta\right) = \frac{\left(p_{k,t}^s - \hat{p}_{k,t}^s\right)^2}{2\left(\sigma_{k,t}^s\right)^2} + \ln\left(\sigma_{k,t}^s\right) + 0.5\ln(2\pi)$$

The likelihood for research diver sampling is analogous. Errors in the tag-recapture dataset were also assumed to be normal. For the jth record, the total error is a function of the predicted standard deviation (equation (27)) and the observation error:

(34) $$\sigma_j^{tag} = \sqrt{\sigma_{obs}{}^2 + \left(\sigma_j{}^d\right)^2}$$

and the negative log-likelihood is:

(35) $$-\ln(\mathbf{L})\left(\hat{d}_j \mid \theta\right) = \frac{\left(d_j - \hat{d}_j\right)^2}{2\left(\sigma_j^{tag}\right)^2} + \ln\left(\sigma_j^{tag}\right) + 0.5\ln(2\pi)$$

The proportion mature-at-length was assumed to be normally distributed, with standard deviation analogous to proportions-at-length:

(36) $$\sigma_k^{mat} = \frac{\tilde{\sigma}}{\varpi^{mat} \sqrt{p_k^{mat} + 0.1}}$$

The negative log-likelihood is:

(37) $$-\ln(\mathbf{L})\left(\hat{p}_k^{mat} \mid \theta\right) = \frac{\left(p_k^{mat} - \hat{p}_k^{mat}\right)^2}{2\left(\sigma_k^{mat}\right)^2} + \ln\left(\sigma_k^{mat}\right) + 0.5\ln(2\pi)$$

2.2.9.2 Normalised residuals

These are calculated as the residual divided by the relevant σ term used in the likelihood. For CPUE, the normalised residual is

(38) $$\frac{\ln\left(I_t\right)-\ln\left(\hat{I}_t\right)}{\left(\sigma_t^I \tilde{\sigma} \big/ \varpi^I\right)}$$

and similarly for PCPUE and RDSI. For the CSLF proportions-at-length, the residual is

(39) $$\frac{p_{k,t}^s - \hat{p}_{k,t}^s}{\sigma_{k,t}^s}$$

and similarly for proportions-at-length from the RDLFs. Because the vectors of observed proportions contain many empty bins, the residuals for proportions-at-length include large numbers of small residuals, which distort the frequency distribution of residuals. When presenting normalised residuals from proportions-at-length, we arbitrarily ignore normalised residuals less than 0.05.

For tag-recapture data, the residual is

(40) $$\frac{d_j - \hat{d}_j}{\sigma_j^{tag}}$$

and for the maturity-at-length data the residual is

(41) $$\frac{p_k^{mat} - \hat{p}_k^{mat}}{\sigma_k^{mat}}$$

2.2.9.3 Dataset weights

The relative weights used for each dataset, ϖ, are relative to the tagging dataset, which is unweighted. Weights were chosen experimentally in choosing a base case, iteratively changing them to obtain standard deviations of the normalised residuals (*sdnr*) close to unity for each dataset.

2.2.9.4 Priors and bounds

Bayesian priors were established for all estimated parameters. Most were incorporated simply as uniform distributions with upper and lower bounds arbitrarily set wide so as not to constrain the estimation. The prior probability density for M was a normal-log distribution with mean μ_M and standard deviation σ_M. The contribution to the objective function of estimated $M = x$ is:

(42) $$-\ln(\mathrm{L})(x \mid \mu_M, \sigma_M) = \frac{\left(\ln(M)-\ln(\mu_M)\right)^2}{2\sigma_M{}^2} + \ln\left(\sigma_M\sqrt{2\pi}\right)$$

The prior probability density for the vector of estimated recruitment deviations, ε, was assumed to be normal with a mean of zero. The contribution to the objective function for the whole vector is:

$$(43) \qquad -\ln(\mathrm{L})(\varepsilon \mid \mu_\varepsilon, \sigma_\varepsilon) = \frac{\sum_{i=1}^{n_\varepsilon} (\varepsilon_i)^2}{2\sigma_\varepsilon^{\ 2}} + \ln(\sigma_\varepsilon) + 0.5\ln(2\pi).$$

2.2.9.5 Penalty

A penalty is applied to exploitation rates higher than the assumed maximum (equation 10); it is added to the objective function after being multiplied by an arbitrary weight (1E6) determined by experiment.

AD Model Builder™ also has internal penalties that keep estimated parameters within their specified bounds, but these should have no effect on the final outcome, because choice of a base case excludes the situations where parameters are estimated at or near a bound.

2.2.10 Fishery indicators

The assessment is based on the following indicators calculated from their posterior distributions: the model's mid-season recruited and spawning biomass from 2005 (current biomass), from 2008 (projected biomass), from the nadir (lowest point) of the population trajectory (*Bmin* and *Smin*) and from a reference period, 1985–87. This was a period when the biomass was stable, production was good and there was a subsequent period when the fishery flourished. The means of values from the three years were called *Sav* and *Bav* for spawning and recruited biomass respectively. We also used annual exploitation rate in 2005, *U05*, and in 2008, *U08*. Ratios of these reference points are also used.

Six additional indicators are calculated as the percentage of runs in which:

- spawning biomass in 2008 had decreased from 2005: *S08<S05*
- spawning biomass in 2008 was less than the reference level: *S08<Sav*
- spawning biomass in 2008 was less than the nadir: *S08<Smin*
- recruited biomass in 2008 had decreased from 2004: *B08<B05*
- recruited biomass in 2008 was less than the reference level: *B08<Bav*
- recruited biomass in 2008 was less than the nadir: *B08<Bmin*

2.2.11 Markov chain-Monte Carlo (McMC) procedures

AD Model Builder™ uses the Metropolis-Hastings algorithm. The step size is based on the standard errors of the parameters and their covariance relationships, estimated from the Hessian matrix.

For the McMCs in this assessment we ran single long chains that started at the MPD estimate. The base case was 5 million simulations long and we saved 5000 regularly spaced samples. For sensitivities we made chains of 2.5 million, saving 5000 regularly spaced samples. In all McMC trials we fixed the value of $\tilde{\sigma}$ to the estimated MPD value because it may be inappropriate to let a variance component change during the McMC.

2.2.12 Sensitivity trials

These involved trials based on the MPD estimates and other trials based on full sets of McMC simulations.

For the MPD trials, datasets were removed one at a time (seven trials), the model was fitted to a single CPUE series from 1983 through 2005, based on catch per diver day, and the linear growth model was used. For the single CPUE series only, the data were iteratively re-weighted to balance the *sdnrs*; in all trials the weights were left as in the base case.

The McMC trials comprised retrospective trials in which data (except for tag-recapture data) were removed one year at a time for comparison with the base case. Two and half million McMC simulations were made in each trial and 5000 samples saved.

Two McMC trials were made in which the assumed maximum exploitation rate, U^{max}, was changed from 0.80 in the base case to 0.65 and 0.90. Finally, an "implicit prior" trial fitted the model with the function value contributions from the data multiplied by a small number, 1E-17. The fit was therefore determined by the prior distributions assumed, penalties and the model structure.

2.2.13 Projections

Stochastic projections were made through 2008 by running the dynamics forward in time with each of the 5000 parameter vectors, driving the model with a specified catch vector (see below). The sequence of operations was as described for the main dynamics.

Recruitment in projections was stochastic, obtained by re-sampling the recruitments estimated from 1995 to 2004. Because the 2005 recruitment deviation is poorly determined by the data (it has no effect on any of the quantities being fitted), the estimated value is inappropriate for projections and was over-written with values obtained by re-sampling.

Projected exploitation rate in projections is limited by simply truncating it at the specified maximum. An indicator is calculated to show, for each projection, the mean of actual catches (exploitation rate times available biomass) as a percentage of the specified catch. In this assessment the actual catch was never less than specified catch and we do not show this indicator.

3. DATA

3.1 Catch data

3.1.1 Commercial catch

The catch history was estimated by Murray & Akroyd (1984) for 1974–83, who stated that landings before 1974 were unreliable. Schiel (1989) presented estimates for 1984–88. Schiel (1992) revisited the estimates for 1981–85, and previous PAU 7 assessments have used the Schiel (1992) estimates as a base case. The effect of this change (affecting mostly the 1981 and 1982 catches) was explored by Andrew et al. (2000a) and found to be small. The 1986 catch appears suspiciously low, and as in previous years we used the average of 1985 and 1987 catches (Table 1).

Catches from 1989 onwards were captured on QMR forms and reported in Plenary documents (e.g. Annala et. al. 2003). Catches used in 2003 assessment (Breen & Kim 2003) were used, and recent data were supplied by MFish. The industry agreed to shelve 15% of the TACC for

2005, but may subsequently "unshelve" some, so for the 2005 catch we assumed 85% of the TACC plus 10 t.

3.1.1.1 Commercial catch in areas 17 and 38

Nearly all catch in 1990 and 1991 came from areas 17 and 38 (Table 1 and Figure 2). These are the areas in which all but the most recent research diver surveys have been made, and the previous assessments (Breen et al. 2001; Breen & Kim 2003) limited the assessment to those two areas.

To estimate the annual commercial catches from areas 17 and 38, we used the QMR catch from all of PAU 7 and the annual proportions that came from areas 17 and 38 estimated from CELRs or PCELRs. Before 1990, the proportion of the total catch reported on CELR forms was too low to support this method, but the proportion of catch from outside areas 17 and 38 appeared to be very low. For the 2005 catch we used the mean proportion from the previous five years.

3.1.1.2 TACC

The TACC was set at 250 t when paua entered the QMS in 1987. This increased to a peak of 266.5 t in 1996 after quota appeals. For 2001, the industry agreed to shelve 20% of their quota; for 2002 the TACC was reduced to 240.7 t; TACC was reduced again for the 2003 season to 187.24 t (Table 1). For the 2004 and 2005 seasons, the industry voluntarily shelved 15% of the TACC, although this might be partially reversed for the last part of 2005.

3.1.2 Recreational catch

The Working Group agreed to assume that recreational catch was 5 t in 1974 and 15 t in 2000 and afterwards, with a linear increase between 1974 and 2000 (Table 1).

3.1.3 Illegal catch

Illegal catch was estimated by the Ministry of Fisheries to be 10–20 t (Paul Cresswell, MFish, pers. comm.). No historical estimates are available. The Working Group agreed to assume that illegal catch was 1 t in 1974 and that it increased linearly to 15 t between 1974 and 2000 (Table 1), remaining at 15 t from 2000 through 2005. For projections the Working Group agreed to assume that illegal catch would fall linearly to 7.5 t by 2008.

3.1.4 Customary catches

Customary catch was incorporated by the Minister of Fisheries into the PAU 7 TAC as an allowance of 8 t (Paul Cresswell, MFish, pers. comm.). No historical estimates are available. The Working Group agreed to assume that customary catch was 4 t in 1974, increasing linearly to 8 t between 1974 and 2000, then remaining at 8 t (Table 1).

For areas 17 and 38, the commercial catch is by far the largest component of the total catch (Figure 3).

3.1.5 Projected catches

For the McMC sensitivity trials, "projections" used the estimated 2005 catch for years after 2005 and the actual catch for years before 2005 (Table 2).

In the base case and McMC sensitivity trials, projections assumed that catch for each year, 2005–08, were the same as the value used for 2005, discussed below. MFish also requested a set of projections with a variety of catches, based on 100% of the TACC down to 0% in 5% increments. For these projections the Working Group agreed to assume that the illegal catch would decrease from 15 t to 7.5 t over the period 2005–08 and that other non-commercial catches would remain the same. The catches used for these projections are shown in Table 3.

3.2 CPUE

3.2.1 CPUE

This year (2005), CPUE indices were calculated separately for the CELR and PCELR reporting forms, changing from the former to the latter for 2002 and later years. For the CPUE index, obtained from CELRs, we used the same groomed data as the 2003 assessment, but only through 2001 (18 564 records).

In the 2003 assessment, the index was restricted to data from vessels that fished for 5 years or longer. In 2005, we used only records from vessels that fished the top 75% of catch in any given year, reducing the number of records to 15 152. About one-third of the vessels land 75% of the catch (Table 4). Records from 137 vessels were used for the CPUE analysis and numbers of vessels chosen in each year are shown in Table 4. Their pattern of involvement in the fishery is shown in Table 5.

As in previous assessments, we used diver-day as the unit of effort for CPUE. The diver-hours field on the CELR forms included a high proportion of obvious errors and was not used. Raw data ranged from 2 to 1944 kg per diver day. Of the data described, 13 857 records were from statistical areas 17 and 38.

The standardisation was done on the natural logarithm of catch per diver day (Vignaux, 1993). There were no zeroes in the groomed dataset. Variables offered to the model were vessel, fishing year, month, statistical area and the month x area interaction. The fishing year was forced to be in the model as an explanatory variable. The order in which variables were selected into the model and their effect on the model r^2 are shown in Table 6. Statistical area did not increase the r^2 substantially (more than 1%) and was not used. The model explained 43.2% of the variation in CPUE for PAU 7. The month x area interaction contributed very little (Table 6) and was not used.

Raw and standardised CPUE for PAU 7 are shown in Table 7 and Figure 4. Standardised CPUE was obtained by multiplying the year effect by the geometric mean of the raw data. The standardised CPUE generally follows the pattern of the raw CPUE. There is a consistent decrease in CPUE from 1983 to 2001.

Vessel effect, which explains most of model variation, is varied from 0.515 to 2.904 as an index.

3.2.2 PCPUE

There were 9669 PCELR records in the 2005 extract. Ten records were removed because they gave no diving hours, 106 because their catch was recorded as "NULL" (18 of these were "NULL" catch in total), 3 because no blackfoot paua were caught (all had "NULL" catch in total), 23 records because they had no statistical area information, 2 because they had no diver key information, 251 because no diving condition was recorded and 12 because catch rate was more than 200 kg per hour.

As for CPUE from CELR, we used only PCELR records from vessels that caught the top 75% of catch in any given year. Records from 32 vessels were used for the PCPUE analysis, each having fished from 1 to 4 years (Table 8 and Table 9). The number of records from 32 vessels was 7300, with 6517 records from statistical areas 17 and 38.

The variables offered to the model were diver, diving condition, vessel, fishing year, month, statistical area, and the area x month and area x diving condition interactions. In the PCELR reporting system there are 97 areas, but only 69 were represented in the data. The fishing year was forced to be in the model as an explanatory variable. The number of unique diver key codes was very high (298 divers), which was unwieldy for the model. Sixty-seven divers who caught less than 50 kg overall were combined and treated as a single diver.

The order in which variables were selected into the model and their effect on the model r^2 are shown in Table 10. The model explained 52.3% of the variation in PCPUE 7. Raw and standardised PCPUE are shown in Table 11 and Figure 5. Standardised PCPUE was obtained by multiplying the year effect by the geometric mean of the raw data. The standardised PCPUE generally follows the pattern of the raw data.

Ranges of other variable effects are shown in Table 12 as an index (i.e. multiplier term). The diver effect ranged from 0.203 to 2.823, vessel effect ranged from 0.815 to 2.228, and statistical area effect with interaction term added ranged from 0.043 to 8.208.

3.3 Research diver survey index (RDSI)

Fishery-independent research diver survey estimates of relative abundance (RDSI) have been made since 1993 (Andrew et al. 2000b). As in the previous assessment for PAU 7, we used a standardised index for CPUE based on the natural log of the abundance index from each swim, which in turn was based on the number and size of paua patches seen in 10 minutes. The dataset (876 swims) contained 28 zeroes, which were removed. These were distributed among years as follows: 1993: 1; 1996: 2; 1999: 4; 2001: 3; 2003: 13; 2005: 5.

The standardised result was then changed into canonical form as described by Francis (1999), giving estimates that are independent of the reference year.

In calculating the RDSI before 2004, the mean size of each patch type was assumed to be the median of the size range of each patch type. Research divers now count the number of paua in all patches, so we calculated mean size for each patch type (Table 13) and used this to calculate the index for the earlier data from 1992 to 1996. For the later data the index is based on the number counted.

As for the 2004 assessment for PAU 4 and PAU 5A (Breen & Kim 2004a, 2004b) the abundance count was scaled by searching time. When divers are underwater it takes an estimated 7.8 seconds per patch (McShane et al. 1996) to count the number of paua, collect a sample and record the patch size. Divers now count patch sizes, but this does not increase patch handling time very much, and divers stop their watch when the patch size looks larger than 20. So total time spent searching in the ath 10-minute swim can be estimated as:

$$t_a^{searching} = 600 - 7.8 n_a^{patches}$$

The raw timed-swim index IS'_a is then modified by rescaling:

$$IS_a = \frac{600 IS_a'}{t_a^{searching}}$$

where IS_a is the scaled count per 10-minute swim. Exploratory analyses in 2004 showed that incorporating the estimated searching time gave a better fit, so this approach was adopted.

The visibility code data were not available at the time of analysis and so were not used in the analysis. A summary of the research diver survey dataset is shown in Table 14.

There were six strata in statistical areas 17 and 38 of PAU 7. Research diver surveys in the Campbell stratum that straddled statistical areas 17 and 38 (see Figure 1) in recent diver surveys, and data from statistical area 18, were excluded from the analysis.

Variables offered to the model were fishing year, stratum, diver and the stratum x diver interaction, with fishing year forced to be an explanatory variable. Month was not offered as a variable because there was no consistency in month surveyed. The order in which variables were selected into the model and their effect on the model r^2 are shown in Table 15. All variables were important for the relative abundance index for PAU 7. The model explains 23.4% of the variation in RDSI.

Raw and standardised diver survey indices with confidence intervals are shown in Table 16 and Figure 6 (the raw index is the arithmetic mean of the indices from each swim). There is only a small difference in raw and standardised research diver survey indices, and the confidence intervals are wide.

Range of stratum effect is from 0.98 to 16.1 as an index.

3.4 Commercial catch sampling length frequency data (CSLF)

Length frequencies were measured in samples of shells from the commercial fishery from 1990 to 1994 and 1998 to 2005 (Table 17 and Table 18). We used only the samples known to have been taken from areas 17 or 38. Weighted length frequencies, $L_{s,area,year}$, where *s*, *area* and *year* index size, statistical area and year, were calculated by scaling the raw length frequency, $L'_{s,area,year}$, by the normalised catch in each statistical area and fishing year:

$$L_{s,area,year} = \frac{L'_{s,area,year} C_{area,year}}{\left(C_{017,year} + C_{038,year}\right)/2}, \text{ where area is either 17 or 38.}$$

Data from areas 17 and 38 are roughly consistent with each other (Figure 7).

The data are shown aggregated across statistical areas 17 and 38 for each year in Figure 8. The 2001 to 2005 fishing years showed the smallest abundance of large paua. Mean length in the dataset (Figure 9) decreased sharply between 2000 and 2003, and has recently increased slightly.

3.5 Research diver survey length frequency data (RDLF)

Research divers remove some paua from each surveyed patch for measuring at the surface to obtain length data from each swim. After calculating research diver survey indices, we linked the calculated abundance from each timed swim to the length frequency data for that timed swim. We calculated the weighted length frequency at size s from the ath timed swim, $L_{s,a}$, by scaling the raw frequency at size s, $L'_{s,a}$, by the normalised abundance from sample a:

$$L_{s,a} = L'_{s,a} \frac{IS_a}{\sum_a IS_a / n_a}.$$

where n_a is the number of swims involved where the abundance data are available for the length frequency data. There were 28 051 paua measured. The number of paua measured in each stratum in each year is shown in Table 19. We used only those years in which at least four strata had been sampled.

The RDLF data by fishing year (Figure 10) show a difference, with fewer large paua in recent years. Sizes varied among strata (Figure 11), so the uneven coverage of strata seen in Table 19 may have contributed to variability in length frequencies between years, as discussed by Andrew et al. (2000b). The mean size of paua in this dataset (Figure 12) shows a decline from 1996 to 2005.

3.6 Growth increment data

The growth increment data used for 2003 stock assessment for PAU 7 (Breen & Kim 2003) were used for the 2005 stock assessment because no additional data had been collected from the area being assessed. Grooming was not revisited; the same data file was used.

3.7 Maturity data

Estimated maturity-at-length affects only the model's estimates and projections of spawning biomass. Data had been collected from one site at Staircase and six sites at D'Urville in March and May 1994. More data were collected during January 2005 during research diver surveys at Perano and Rununder. Paua were checked for maturity and for sex if mature. In all, 414 paua were examined. Data were aggregated for the assessment across all areas and dates. They were collated as the number examined and the number mature in 2-mm length bins (Table 20).

4. MODEL RESULTS

This section first shows the MPD results from the base case, which was chosen by adjusting the relative weight parameters for each dataset until the standard deviations of standardised residuals were close to 1.0 for each dataset. Sensitivities to the influence of datasets and modelling options were explored by comparing MPD runs.

Second, we show diagnostics from one long McMC chain for the base case model. Third, we show the Bayesian fits and residuals from these fits. Fourth, we show results of McMC sensitivity trials. The assessment is obtained from the posterior distributions of a set of indicators based on biomass and exploitation rate at three times: the present, at the end of three-year projections, and the reference period, 1985–87.

4.1 Finding a base case

The base case was chosen by altering the relative weight of each dataset until the standard deviations of the normalised residuals were close to 1.0 for each dataset. The specifications for estimated parameters are shown in Table 21. Fixed values for the base case are shown in Table 22.

The Working Group discussed the value assumed for maximum exploitation rate, U^{max}, and agreed that this should be 0.65. However, with this value *M* became very high, the function value was far greater than it was when 0.80 was used and the model's response to iterative re-weighting became confused. We chose therefore to use $U^{max} = 0.80$ for the base case.

The model gives a choice of linear or exponential growth models, and we used the exponential one in the base case.

4.2 MPD results

Base case parameter estimates and some indicators are shown in the first data column of Table 23, with the base case denoted as "001". The weights chosen gave standard deviations of normalised residuals that were very close to 1 for all data sets except PCPUE. The model fitted this small dataset closely; the responsiveness to increased weight was low; and we chose to accept a lower *sdnr* for this dataset.

The MPD estimate of *M* was 0.149, somewhat larger than the assumed mean of the prior distribution, 0.10 (Table 23). The value of *X* was 0.192. This value determines the relation between the scalars for CPUE, in kg per day, and PCPUE, in kg/hour, and is very close to the inverse of the mean number of hours per days in the PCELR data, 5.25 (inverse 0.1906). Thus the estimated *X* is a highly reasonable value.

The model estimated *h* as 0.64, giving a relation between CPUE and biomass with some hyperstability (Table 23). This is what one would expect from abalone populations, where divers can maintain high catch rates as the stock is fished down.

The base case model fits the two observed CPUE abundance indices creditably (Figure 13); it is unable to fit the RDSI index closely, but the fit captures the decrease to 2000 and subsequent increase (Figure 13). Residuals are reasonable given the sparse data (Figure 14). The fit to maturity-at-length is good (Figure 15).

Fits to proportions-at-length were reasonably good (Figure 16) and there was no consistent relation between the residuals and length (Figure 17). The means of residuals at length show some pattern (Figure 18), especially near the MLS. The q-q plot for normalised residuals from the RDLF data is a bit better formed than that from the CSLF (Figure 19), but both are reasonable between values of -2 and 2.

The fit to growth increment data (Figure 20) is generally acceptable except that where tags were not recovered until more than 600 days later, the model tended to over-estimate the increment. These tags were all from the same experiment at one site, so this could be a bias caused by the long time at liberty or could be caused by growth differences among sites. Figure 21 shows the q-q plot for normalised residuals for all datasets combined. The expected annual growth increment is also shown, with the standard deviations, in Figure 22 (top).

The midpoint of the research diver selectivity ogive (Figure 22, middle) was 103.6 mm, and the ogive was broad as in previous assessments. The midpoint of the commercial fishery selectivity (Figure 22, bottom) was 123.96 mm, just under the MLS, and this ogive was very narrow.

The model's MPD estimates of recruitment (Figure 23, top) were lower than average in the mid to late 1990s and higher than average in 2004.

Exploitation rate (Figure 23, bottom) increased steadily over the history of the fishery, reached the maximum of 80% in 2000 and 2003 but shows a strong recent decline to 60% in 2005.

The unfished length frequency (Figure 24) has a mode at 80 mm and has substantial numbers of large paua. Recent proportions-at-length still have many small paua and far fewer larger paua. The model recruitment plotted against the model's spawning biomass two years earlier (Figure 25) shows no obvious relation.

The MPD biomass trajectories, the surplus production trajectories and surplus production plotted against the recruited biomass are shown in Figure 26. Total biomass includes all animals. Recruited biomass involves those animals at or above the MLS. Available biomass involves those animals available to the commercial fishery (equation 7). Estimated biomass decreased substantially from the 1965 estimate until the turn of the century, then spawning and recruited biomass show slight increases. Surplus production increased as biomass decreased, to a maximum in the early 1990s, then declined to 2000 and shows a recent increase. Surplus production plotted against biomass suggests a maximum near 500 t, at about one-sixth of the unfished biomass, but this is based on a one-way trip and should be treated cautiously.

4.3 MPD sensitivity trials

Sensitivity trials based on MPD results involved removing the datasets one at a time to see how they affected the model's results, fitting to a single standardised CPUE series based on catch per diver day and making the growth model linear instead of exponential. Results are summarised in Table 23.

When the model was fitted to one data set at a time, recruitment estimates increased markedly when CPUE or tag-recapture data were removed, or when the linear growth model was used. M estimates also increased when CPUE was removed or the linear growth model was used. Removal of CPUE and tag data also had an effect on the research diver selectivity estimates. Removal of the tagging data caused the model to make much lower estimates of growth parameters. Apart from these changes, sensitivity trials did not have much effect on parameter estimates, except where the data set removed contained the only information about the parameter.

Indicators were remarkably stable in these trials. The main exception was when tag-recapture data were removed, which caused large increases in all biomass estimates. Removal of CPUE caused a decrease in estimated *Bav*. Using one continuous CPUE series led to slightly less optimistic biomass ratio indicators.

4.4 McMC results

The McMC traces (Figure 27) showed good mixing. The main diagnostic we used was to plot the running median and 5th and 95th quantiles of the posterior and the moving average calculated over 40 samples (Figure 28). Moving means for recruitment and M showed an excursion and return very late in the chain, but there is no strong evidence that the chain is not converged.

The McMC parameter correlation matrix (Table 24) shows a high correlation between recruitment and M, as is usually seen; between the c.v. of growth and the other two growth parameters; between the first research diver selectivity parameter and recruitment, M and growth; between the two commercial fishery selectivity parameters; and among the abundance scalars and shape parameter. This list does not seem excessive.

4.5 Marginal posterior distributions and the Bayesian fit

Posteriors (Figure 29) were generally well formed and MPDs were mostly near the centres (but tended to be below the median of biomass posteriors). Posteriors of the *sdnr*s were mostly in the range from 0.8 to 1.2 except for PCPUE. The posteriors are summarised in Table 25. The indicator *Bmin* was tightly estimated; other biomass estimates were less tight. Recruited biomass tended to be estimated more precisely than spawning biomass.

The posteriors of fits to CPUE (Figure 30) show that variation was greatest for the early years, where data are weakest, and was low for the recent years. Some years have predictions that do not encompass the observed values, but there is no pattern in the residuals. The posterior fits to PCPUE (Figure 31) and RDSI (Figure 32) also fit the data well, although the model seems unable to reproduce the range of variation seen in the RDSI data.

The posteriors of predicted CSLFs for 2002, when both CSLF and RDLF data were available, (Figure 33) were very tight and did not match the observed values for the two peak size bins just above the MLS. The residual pattern was worse for RDLFs in the same year (Figure 34), although the overall fit was acceptable.

The posteriors of the fits to tagging data are difficult to show; instead we show the posterior of the q-q plot of the residuals (Figure 35), showing a moderately poor fit that is probably related to the influences of proportion-at-size datasets on the growth estimates.

The fit to maturity data (Figure 36) is tight because only this single data set contains any information about maturity.

The biomass trajectory posteriors (Figure 37) are widest for the earliest years, and for recruited biomass are very narrow near 2000, where the exploitation rate estimates were limited by the assumed maximum. All show recent and projected increases.

In all three biomass measures, the stock declined from 1965 to 2001. Recruited biomass then increased slightly to 2005. The projections at current assumed catch levels show a strong increase with increasing uncertainty over the three projection years. The recruited biomass trajectory is shown in more detail in Figure 38.

Exploitation rate (Figure 39, top) was similar to the MPD trajectory and shows a strong decrease in projections. Median recruitment (Figure 39, bottom) is also similar to the MPD, but individual estimates show high uncertainty (although higher or lower than average estimates are always higher or lower than average).

The surplus production trajectory (Figure 40) was similar to the MPD, with high variability in the 1980s and low variability near 2000. The posterior distribution of production as a function of recruited biomass (Figure 41) suggests high productivity at low stock size.

4.6 Comparison with 2003

Distributions of parameter estimates, for parameters common to both assessments (but excluding the recruitment deviations), are very similar (Table 26). The *q*s for CPUE could not be compared because the units were changed in the 2005 assessment, using standardised CPUE rather than the year effect. The major difference is a higher *M* in 2005 (median 0.150 *vs* 0.123). Spawning biomass was slightly higher in 2005, a direct result of the higher *M*.

Biomass trajectories (Figure 42 and Figure 43) are virtually identical for recent years, although they differ in the early years for which no data were available. The reasons for this early divergence include the different model starting dates and the different approach to early catches. Exploitation rates are virtually identical through 2003 (Figure 44). Estimated recruitment was somewhat lower in 2003 than in 2005 (Figure 45), reflecting the lower *M*, but had the same pattern.

This comparison shows that the 2005 assessment is not substantially different from the 2003 assessment, as might be expected: there are only slight changes in the data, two more years' data, and one small change to the model.

4.7 McMC sensitivity trials

4.7.1 Retrospectives

In the retrospective McMC sensitivity trials the data (except for tag-recapture data) were removed from the fitting one year at a time, from 2005 through 2002, for comparison with the base case, in which the last year of data was 2005.

The model results were generally stable to removal of data until the 2002 data were removed (Table 27), and even then the change was not dramatic. Most parameter values remained near the base case values; ln(*R0*) in particular was stable until 2002 data were removed, then it and other values increased.

Consequently, biomass trajectories were similar (Figure 46), at least from 1985 forward. There are little data before then, and the sensitivity of early biomass estimates suggests that *B0* would be a poor reference point. Projections, shown in Figure 47, are similar among the trials except for the 2001 trial, which shows a much stronger increase. These results are mirrored in the exploitation rate trajectories (Figure 48). Recruitments (Figure 49 and Figure 50) show similar patterns among the trials except for the final few years.

4.7.2 Maximum exploitation rate trials

When the assumed maximum exploitation rate was changed, substantial change occurred when 0.65 was assumed (Table 28); in particular, recruitment (Figure 51) and *M* were much larger and the fit to the data was worse, as reflected in the function value. Research divers were estimated to be much less sensitive to small paua. Biomass indicators were all larger, as would be expected, but spawning biomass indicators were double because of the larger numbers of sublegal mature paua caused by the increased *M*. Recruited biomass trajectories (Figure 52) were more complex: for 0.65 the historical biomass was much less than the base case; recent biomass was higher. Projection indicators involving recruited biomass were similar to but less optimistic than the base case. Exploitation rates (Figure 53) followed the same pattern.

The 0.90 trial fitted the data better than the base case; biomass indicators were slightly smaller; but projection indicators were similar.

4.7.3 Implicit prior trial

Results from this trial suggested that the model structure and assumed priors have little effect on the model results. The parameter posteriors (see Table 29) are wide and appear to be consistent with the priors (Table 21); their medians bear no relation to the base case. The biomass trajectories are flat (Figure 54) and biomass is very large. Exploitation rates (not shown) never exceed 2%. The posteriors of *M* and recruitment deviations (Figure 55 and Figure 56) are the same as the assumed priors.

4.8 Projections with alternative catches

Results from these projections are shown in Table 30 (medians of posteriors and percentage indicators), Table 31 (5th quantiles of posteriors) and Table 32 (95th quantiles).

The medians of all projections show an increase in spawning biomass over the next three years at all levels of alternative catch, even the one in which the entire TACC was assumed to come from areas 17 and 38. If the catch is restricted to 15% of the TACC or less, the 5th quantiles also show an increase. The risk of a decrease in spawning biomass is 15% with no catch reduction (774 runs out of 5000) and decreases quickly with reduced catch. Over three years, the median spawning biomass would not reach *Sav* except at very high catch reductions, but would be 75% of *Sav* even with no catch reduction (see Table 30).

Median recruited biomass shows a strong increase in the projections for all catch levels and is highly responsive to the level of catch. The projected 2008 biomass varies from 160% to 440% of the 2005 biomass, depending on catch (Table 30, Figure 57).

5. AREAS 18 AND 36

The assessment described above was based on statistical areas 17 and 38, as discussed above. The Working Group requested that we work up and present the available data for the two other statistical areas, 18 and 36 (see Figure 1).

Catch has been highly variable from these two areas (Table 33 and Table 34). Overall, the catch has been much greater from area 18. The combined catch was negligible until the early 1990s, rose to a peak in 2001 near 90 t and then declined to 14 t in 2004.

Raw CPUE shows some very high values in 1986–88, based on only 5 days' fishing in area 36 (Table 33, Figure 58), but after that shows no pattern. Raw PCPUE is also distorted by low fishing effort in area 36 (Table 34, Figure 59), is slightly higher than, and shows a similar pattern to, areas 17 and 38 (see Table 11).

Research dive surveys are very sparse (Table 35), with a survey in both areas in 2003, and only two swims, both in area 18, subsequently. Thus there is no chance to explore the data for trends in abundance. There are concomitantly few RDLF data (Table 36); these show populations dominated by large paua, with relatively few small paua (Figure 60 and Figure 61).

CSLF data from these areas are summarised in Table 17, shown in Figure 62 and compared with areas 17 and 38 in Figure 63. The populations in areas 18 and 36 are dominated by large paua and do not show the steep decline with size above the MLS seen in areas 17 and 38. The pattern of sizes above the MLS is similar to that seen in the unfished population estimated by the model (Figure 24). Figure 63 shows the data from areas 18 and 36 combined, plotted by area: there is no clear trend with time and the mean lengths (Figure 64) also show no trend.

Paua were tagged in the Cape Campbell stratum on 27 August 2003 and 9 were recovered 383 days later. Their growth increments are shown in Figure 65.

The best that the data from areas 18 and 36 allow one to say is that catch has been variable, raw CPUE shows no trend, and the size structure in these areas differs from that in areas 17 and 38 and is consistent with an undeveloped (or sequentially depleted) fishery.

6. DISCUSSION

6.1 Model performance

The diagnostics for this assessment were favourable. During searching for the base case MPD the model fitted the data comfortably and the residuals were balanced easily; there were no symptoms of trouble such as badly formed Hessians, excessive numbers of function evaluations, sensitivity to phasing, or starting values. Some of these problems were observed when we used the 2004 model. Their specific causes, which must be one or more of the model changes made in 2004, such as the revised growth model, have not been determined.

Sensitivity of the MPD indicators to dataset removal and other modelling choices was not great. M was sensitive to removal of the CPUE series (the longest abundance index series) and to using the linear growth model, but the indicators were not greatly affected. Growth estimates were sensitive to removal of the tag-recapture data set: the model estimated much slower growth when these data were absent, but again the indicators did not change much.

Lack of sensitivity to dataset removal suggests redundancy of information among datasets. Another positive diagnostic is that the model is able to estimate X at a value consistent with external analysis. The model might have allowed a substantial change in abundance between 2001 (the end of the CPUE series) and 2002 (the beginning of the PCPUE series) and compensated for this change by adjusting the scalars. That it did not do this suggests good information about abundance trends outside the CPUE abundance indices.

The MPD fit was best when higher values were assumed for maximum exploitation rate, and reducing the assumption to 0.65 led to a poor fit, unrealistically high M and other symptoms of poor performance. This is the major source of uncertainty with respect to the MPD fits.

The diagnostics for McMC simulations were acceptable. Retrospectives were generally stable until four years of data had been removed, when model predictions became far too optimistic. The 2002 data contain some important information, which by elimination must be in the CSLF data set (see Table 2), so is likely to be the decrease in larger paua (see Figure 9). The "implicit prior" trial showed that results are driven by the data, not by the model structure and priors.

As it was for the MPD, the assumed value of U^{max} is the major uncertainty. Increasing this from 0.80 to 0.90 has a small effect, but decreasing it to 0.65 increased M and made projection indicators less optimistic. Although the high M estimates appear to be unrealistic, the tendency for projected biomass increases to be weaker with decreased U^{max} must be noted.

6.2 PAU 7 assessment

It cannot hurt to repeat that the assessment addresses only areas 17 and 38 within PAU 7. These areas supported most of the catch until recently, and most of the data come from them, but the relation between this subset of PAU 7 and PAU 7 as a whole is uncertain.

The assessment shows a depleted stock. The current spawning and recruited biomass levels are both much lower than they were when the catch data begin in 1974 or CPUE data begin in 1983 (see Figure 37). Both are lower than the agreed target reference levels from 1985–87: spawning biomass has a median of 68%, with a 95% confidence interval of 64–73%; recruited biomass has a median of 22% (19–25%). Both are above the agreed limit biomass reference points. Current exploitation (poorly determined because it depends on the assumed value for U^{max}) is estimated to be 60% (58–62%).

The tight ranges for most model estimates derive from the model's exploitation rate reaching its bound, U^{max}. Sensitivity trials show that assuming other values for U^{max} has little effect on recent biomass estimates and trends, but assuming 0.65 leads to unrealistic M estimates and quite different biomass trajectories. The target reference points are sensitive to U^{max} but the limit reference points are not. This is the major uncertainty of the assessment.

Although the stock is depleted, model projections show a very strong probability of increase in both spawning and recruited biomass (see Table 30 to Table 32), even if the whole TACC were removed from areas 17 and 38. The risk of spawning biomass decrease would be 15% at that catch level, but this decreases very quickly with decreased catch. In projections, there was no risk of recruited biomass decline at any catch level.

The speed of rebuilding towards reference levels depends on catch levels (see Figure 57). At no level of catch does median recruited biomass reach the reference level in three years, and for spawning biomass this happens only with very large catch reductions. Three years is an unrealistic time for reaching the reference levels, given the dynamics of this species and the current levels of depletion.

6.3 Cautionary notes

6.3.1 The McMC process underestimates uncertainty

The base case assessment results described above have more uncertainty than that reflected in the posterior distributions. These results come from a single base case chosen from a wide range of possibilities, although the choice of a base case was reasonably objective. The most important uncertainty is the choice of U^{max}, affecting both the estimated current status of the stock and the strength of rebuilding.

Another source of uncertainty outside the model is the 2005 catch. The assessment uses a value based on partial returns, because the year is not complete, and uses an estimate of the proportion of PAU 7 catch that comes from areas 17 and 38. Differences between the estimated and actual catch for 2005 in areas 17 and 38 could affect the strength of rebuilding predicted by the assessment.

6.3.2 The data are not completely accurate

The next source of uncertainty comes from the data. The commercial catch before 1974 is unknown and, although we think the effect is minor, major differences may exist between the catches we assume and what was taken. In addition, non-commercial catch estimates are poorly determined and could be substantially different from what was assumed, although generally non-commercial catches appear to relatively small compared with commercial catch. The illegal catch is particularly a suspect.

The tagging data may not reflect fully the average growth and range of growth in this population. Similarly, length frequency data collected from the commercial catch may not represent the commercial catch with high precision: after 1999 the number of paua measured from area 38 has been only 500 or less.

The research diver data comprise seven surveys, but for some the standard errors are quite large (see Figure 6) and length frequencies may not be fully representative of the population.

6.3.3 The model is homogeneous

The model treats the whole of the assessed substock of PAU 7 as if it were a single stock with homogeneous biology, habitat and fishing pressures. This mean the model assumes homogeneity in recruitment, natural mortality, which does not vary by size or year and growth has the same mean and variance (we know this is violated because some areas are stunted and some are fast-growing).

To what extent does a homogenous model make biased predictions about a heterogeneous stock? Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different places; similarly the length frequency data are integrated across samples from many places.

The effect is likely to make model results **optimistic**. For instance, if some local stocks are fished very hard and others not fished, recruitment failure can result because of the depletion of spawners, because spawners must breed close to each other and because the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries. So local processes may decrease recruitment, which is an effect that the current model cannot account for.

6.3.4 The model assumptions may be violated

The most suspect assumption made by the model is that CPUE is an index of abundance. There is a large literature for abalone that suggests CPUE is difficult to use in abalone stock assessments because of serial depletion. This can happen when fishers can deplete unfished or lightly fished beds and maintain their catch rates. So CPUE stays high while the biomass is actually decreasing.

In fully developed fisheries such as PAU 7 this is not such a serious problem. In areas 17 and 38 the exploitation rate has been high and few undepleted areas are likely to remain. The main problem affects the model's estimates of the early fishery, but in this assessment, the degree of hyperstability appeared reasonably well determined.

Another source of uncertainty is that fishing may cause spatial contraction of populations (e.g., Shepherd & Partington 1995), or that some populations become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole. Past recruitments estimated by the model might instead have been the result of serial depletion.

7. ACKNOWLEDGMENTS

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Table 1: Commercial catch and TACC for the PAU 7 assessment. Columns show the source of "All PAU 7" catches, year, the total commercial catch (kg) from PAU 7, the percentage of catch reported to the QMR system that was also reported on the CELR or PCELR systems, the percentage of total catch on the CELR or PCELR systems that came from area 17 and 38, the estimated commercial catch from areas 17 and 38, estimates of illegal, recreational and customary catch, the total catch from areas 17 and 38 and the TACC(t).

Source	Year	All PAU 7	CELR/ QMR	% 17&38	Comm. 17&38	Illegal	Rec.	Cust.	Total 17&38	TACC
Murray & Akroyd (1984)	1974	147440		100.0	147440	1000	5000	4000	157440	
	1975	197910		100.0	197910	1538	5385	4154	208987	
	1976	141880		100.0	141880	2077	5769	4308	154034	
	1977	242730		100.0	242730	2615	6154	4462	255961	
	1978	201170		100.0	201170	3154	6538	4615	215478	
	1979	304570		100.0	304570	3692	6923	4769	319955	
	1980	223430		100.0	223430	4231	7308	4923	239892	
Schiel (1992)	1981	490000		100.0	490000	4769	7692	5077	507538	
	1982	370000		100.0	370000	5308	8077	5231	388615	
	1983	400000	52.40	100.0	400000	5846	8462	5385	419692	
	1984	330000	82.90	100.0	330000	6385	8846	5538	350769	
	1985	230000	75.30	100.0	230000	6923	9231	5692	251846	
Averaged MFish	1986	236090	38.00	100.0	236090	7462	9615	5846	259013	
	1987	242180	45.30	100.0	242180	8000	10000	6000	266180	250.00
	1988	255944	24.40	100.0	255944	8538	10385	6154	281021	250.00
	1989	246029	24.60	100.0	246029	9077	10769	6308	272183	250.00
	1990	267052	80.20	99.8	266509	9615	11154	6462	293740	263.53
	1991	273253	82.90	98.4	268782	10154	11538	6615	297090	266.24
	1992	268309	93.20	93.1	249789	10692	11923	6769	279173	266.17
	1993	264802	90.80	96.3	255045	11231	12308	6923	285507	266.17
	1994	255472	100.50	97.2	248285	11769	12692	7077	279823	266.17
	1995	247108	103.50	96.1	237571	12308	13077	7231	270187	266.17
	1996	268742	91.90	90.1	242057	12846	13462	7385	275749	267.48
	1997	267594	91.40	86.2	230570	13385	13846	7538	265339	267.48
	1998	266655	89.10	81.9	218479	13923	14231	7692	254325	267.48
	1999	265050	86.90	86.5	229198	14462	14615	7846	266121	267.48
	2000	264642	110.60	75.0	198419	15000	15000	8000	236419	267.48
	2001	215920	120.40	65.2	140731	15000	15000	8000	178731	267.48
	2002	187152	97.90	74.3	139114	15000	15000	8000	177114	240.73
	2003	187222	97.50	88.3	165351	15000	15000	8000	203351	187.24
	2004	159551	98.70	91.2	145467	15000	15000	8000	183467	187.24
Assumed	2005	169154		78.8	147536	15000	15000	8000	185536	187.24

Table 2: Data used for retrospective analysis. The columns show the name of each trial (named after the last year of data), the years for which "projections" are made, the number of data points or records for the data shown, and the projected catches.

									Projected catches (kg)
Name	Last Year	Projection Years	CPUE	PCPUE	CSLF	RDLF	Year 1	Year 2	Year 3
2005(base)	2005	2006-08	19	4	12	7	171286	171286	171286
2004	2004	2005-07	19	3	11	6	171286	171286	171286
2003	2003	2004-06	19	2	10	6	183467	171286	171286
2002	2002	2003-05	19	1	9	5	203351	183467	171286
2001	2001	2002-04	19	0	8	5	177114	203351	183467

Table 3: Catches used for projections with alternative catches.

Decrease	TACC	2006	2007	2008
0%	187.24	222740	220240	217740
5%	177.88	213378	210878	208378
10%	168.52	204016	201516	199016
15%	159.15	194654	192154	189654
20%	149.79	185292	182792	180292
25%	140.43	175930	173430	170930
30%	131.07	166568	164068	161568
35%	121.71	157206	154706	152206
40%	112.34	147844	145344	142844
45%	102.98	138482	135982	133482
50%	93.62	129120	126620	124120
55%	84.26	119758	117258	114758
60%	74.90	110396	107896	105396
65%	65.53	101034	98534	96034
70%	56.17	91672	89172	86672
75%	46.81	82310	79810	77310
80%	37.45	72948	70448	67948
85%	28.09	63586	61086	58586
90%	18.72	54224	51724	49224
95%	9.36	44862	42362	39862
100%	0.00	35500	33000	30500

Table 4: Number of vessels in the CELR data and the number of vessels chosen in each fishing year (vessels that landed the top 75% of the catch).

Fishing year	Vessels in data	Vessels used	Fishing year	Vessels in data	Vessels used
1983	26	10	1995	74	27
1984	28	10	1996	61	23
1985	22	8	1997	64	24
1986	15	6	1998	63	21
1987	22	8	1999	57	23
1988	15	5	2000	82	30
1989	33	13	2001	117	43
1990	62	22			
1991	65	22			
1992	81	31			
1993	77	24			
1994	73	23			

Table 5: Number of vessels in the CELR data that fished for specified numbers of years.

No. years	Vessels
1	17
2	24
3	27
4	18
>=5	51

Table 6: The order in which variables were selected into the standardisation model of CPUE and their cumulative effect on the model r^2. Bold indicates the final model.

Variable	Model r^2 (%)
Year	19.5
+Vessel	**43.2**
+Month	43.7
+Area	43.9
+Month x area	44.0

Table 7: Standardised CPUE indices from CELR data for areas 17 and 38 of PAU 7. The standard error shown is on the index in log space.

Fishing year	Standardised CPUE (kg/day)	SE	Diver days
1983	228.8	0.0322	726
1984	225.5	0.0288	1060
1985	220.2	0.0310	626
1986	199.7	0.0384	378
1987	185.2	0.0393	562
1988	196.4	0.0470	373
1989	163.0	0.0429	355
1990	137.7	0.0249	1292
1991	136.3	0.0224	1415
1992	115.6	0.0226	1894
1993	133.0	0.0235	1544
1994	130.9	0.0250	1624
1995	126.0	0.0246	1630
1996	124.6	0.0245	1632
1997	109.9	0.0245	1736
1998	111.1	0.0253	1601
1999	118.8	0.0264	1529
2000	80.7	0.0257	2111
2001	60.0	0.0274	2246

Table 8: Number of vessels in the PCELR data and the number of vessels chosen in each fishing year (vessels that landed the top 75% of the catch).

Fishing year	Vessels in data	Vessels chosen
2002	76	25
2003	62	20
2004	49	18
2005	33	12

Table 9: Number of vessels in the PCELR data that fished for 1 to 4 fishing years.

Year	Vessels
1	2
2	7
3	5
4	18

Table 10: The order in which variables were selected into the standardisation model of PCPUE and their cumulative effect on the model r^2. Bold indicates the final model.

Variable	Model r^2 (%)
Year	0.2
+Diver	34.6
+Area	39.0
+Month	41.4
+Vessel	43.0
+Diving condition	44.5
+Month x area	50.6
+Area x diving condition	**52.3**

Table 11: Standardised PCPUE indices from the PCELR data for areas 17 and 38 of PAU 7. The standard errors are from the canonical indices in log space.

Fishing year	Standardised CPUE (kg/hour)	SE	Diving hours
2002	12.57	0.0120	7699
2003	12.32	0.0100	10226
2004	13.16	0.0098	9415
2005	15.23	0.0159	3253

Table 12: Ranges of other variable effects of the standardisation model from the PCELR data.

Variables	Range
Diver	0.203–2.823
Vessel	0.815–2.228
Statistical area (with interaction term added)	0.043–7.208

Table 13: Definitions of research diver survey patch type by number of paua; the old definition assumed mean number and the new definition uses the actual mean number for PAU 7, shown.

		Average patch size	
Patch type	Patch size	Old	New
0	0	0	0
1	1–4	1.28	1.48
2	5–10	7.5	6.76
3	11–20	15.5	14.05
4	21–40	30.5	28.15
5	41–80	60.5	54.15
6	>80	120.5	155.63

Table 14: Summary of research diver survey data, showing the number of timed swims made in each stratum in each year (a) and each diver in each year (b). The mean count, incorporating searching time, is shown by stratum in (c) and by diver in (d).

(a)

Count						Stratum
Year	Campbell	D'Urville	NthnFaces	Perano	Rununder	Staircase
1993	0	29	28	29	32	0
1995	0	0	30	0	4	4
1996	0	24	0	30	42	6
1999	0	40	38	38	38	10
2001	0	40	32	30	31	9
2003	0	30	29	26	30	12
2005	2	32	30	27	30	12

(b)

Count								Diver
Year	1	2	3	4	5	6	7	8
1993					52		52	14
1995					13		14	11
1996		15		12	18		15	42
1999			23	16		67	54	4
2001						49	47	46
2003	21		29			32	37	8
2005	18		16			43	44	12

(c)

Average						Stratum
Year	Campbell	DUrville	NthnFaces	Perano	Rununder	Staircase
1993		92.12	40.77	52.00	82.63	
1995			96.66		37.06	36.13
1996		211.59		66.98	31.61	105.96
1999		63.05	65.42	67.95	20.55	69.30
2001		53.75	44.59	41.53	38.71	72.11
2003		64.77	51.69	67.54	71.77	56.50
2005	15.00	74.53	85.30	178.96	48.70	63.25

(d)

Average								Diver
Year	1	2	3	4	5	6	7	8
1993					80.13		59.72	49.51
1995					89.03		96.44	62.27
1996		24.65		31.19	168.96		103.51	88.41
1999			100.13	50.88		48.37	44.26	79.00
2001						56.94	35.77	47.85
2003	44.14		61.48			72.28	71.78	43.75
2005	75.17		61.25			110.98	80.80	113.83

Table 15: The order in which variables were selected into the standardisation model of RDSI and their cumulative effect on the model r^2 for PAU 7. Bold indicates the final model.

Variable	Model r^2 (%)
Year	3.6
+Stratum	18.2
+Diver	20.3
+Stratum x diver	**23.3**

Table 16: Standardised RDSI for areas 17 and 38 of PAU 7. The first two columns show the year effect and its standard error; the last column shows the standardised abundance (number per 10-minute swim).

Year	Index	SE	Std RDSI
1993	0.863	0.120	93.8
1995	1.508	0.191	163.9
1996	1.363	0.140	148.2
1999	0.689	0.104	74.9
2001	0.621	0.103	67.5
2003	1.062	0.119	115.4
2005	1.239	0.109	134.6

Table 17: Number of commercial catch sampling days in each statistical area in each fishing year for PAU 7.

Year	17	38	18	36	Unknown	Total
1990	4	4				6
1991	10	8	7			24
1992	17	6	2	2		27
1993	13	6	5			23
1994	19	4	2			24
1998					5	5
1999	20	5	1			24
2000	27	2	4	2	16	31
2001	11	2	5	4	10	19
2002	24	1	8		2	32
2003	20	2	5	1		23
2004	15	2	1		4	18
2005	20		1		5	21
Total	200	42	41	9	42	277

Table 18: Numbers of paua measured in commercial catch sampling by year and statistical area in PAU 7.

Year	17	38	18	36	Unknown	Total
1990	1736	2990				4726
1991	4716	4861	2837			12414
1992	6771	1988	655	643		10057
1993	4552	2475	1623			8650
1994	7037	1715	924			9676
1998					990	990
1999	4143	1056	95			5294
2000	4952	218	424	409	1886	7889
2001	3167	299	773	705	1740	6684
2002	6101	170	1331		337	7939
2003	6927	445	1277	189		8838
2004	3668	506	131		673	4978
2005	4022		136		579	4737
Total	57792	16723	10206	1946	6205	92872

Table 19: Numbers of paua measured in research diver surveys by year and stratum in PAU 7.

Year	D'Urville	Northern Faces	Perano	Rununder	Staircase	Total
1990	333	526		53	127	1039
1992			616	785		1401
1993	1717	63	694	1135		3609
1995		2818		106	492	3416
1996	1621		677	785	491	3574
1999	2076	1714	662	693	524	5669
2001	1680	1125	591	654	437	4487
2003	1618	1016	745	857	438	4674
2005	1576	1459	911	601	452	4999
Total	10621	8721	4896	5669	2961	32868

Table 20: Numbers of paua examined and number mature-at-length in the maturity-at-size study in PAU 7.

Length	No. sampled	No. mature
71	2	0
73	6	0
75	8	0
77	8	0
79	10	0
81	11	1
83	13	3
85	14	4
87	28	8
89	29	13
91	27	12
93	22	11
95	40	27
97	33	30
99	28	27
101	15	15
103	27	27
105	21	19
107	32	32
109	30	29
111	5	5
113	2	2
115	2	2
117	0	0
119	0	0
121	0	0
123	1	1
125	0	0

Table 21: PAU 7 base case specifications: for estimated parameters, the phase of estimation (-1 indicates fixed), lower bound, upper bound, type of prior, (0 uniform, 1 normal, 2 lognormal), mean and standard deviation of the prior; for other variables, values assumed for the base case. "Varied" means fixed in the base case but varied between runs to find a base case.

Variable	Phase	LB	UB	Prior	Mean	Std. dev.
$\ln(R0)$	1	5	50	–	–	–
M	3	0.01	0.5	2	0.1	0.35
g_α	2	1	50	–	–	–
g_β	2	0.01	50	–	–	–
ϕ	2	0.001	1	–	–	–
q^I	1	-30	0	–	–	–
X	1	0.05	1	–	–	–
q^J	1	-30	0	–	–	–
L_{50}	1	70	145	–	–	–
L_{95-50}	1	1	50	–	–	–
T_{50}	2	70	125	–	–	–
T_{95-50}	2	0.001	50	–	–	–
D_{50}	2	70	145	–	–	–
D_{95-50}	2	0.01	50	–	–	–
$\ln(\tilde{\sigma})$	1	0.01	1	–	–	–
h	1	0.01	2	–	–	–
ε	3	-2.3	2.3	1	0	0.4
σ_{MIN}	-2	0.001	5	–	–	–
σ_{obs}	-1	0.001	5	–	–	–

Table 22: Values for fixed quantities in the PAU 7 base case.

Variable	Value
α	75
β	120
ϖ^I	0.050
ϖ^J	0.095
ϖ^r	36.181
ϖ^s	58.796
ϖ^{mat}	4.266
ϖ^{I2}	0.215
$U^{\max}$	0.800
a	2.59E-08
b	3.322

Table 23: MPD sensitivity trials for PAU 7. Columns "002" through "008" present results from trials in which one dataset was removed: CPUE, CSLF, RDLF, tag-recapture, maturity and PCPUE respectively; in the "009" trial a single CPUE dataset was used for 1985-2005; for '010" the growth model was linear. Sdnrs: standard deviations of the normalised residuals; parameters are defined in section 2.2.1. Shading indicates sdnrs inflated because they were not estimated, and likelihood contributions not used when datasets were removed.

	Base "001	No CPUE "002	No RDSI "003	No CSLF "004	No RDLF "005	No tags "006	No maturity "007	No PCPUE "008	One CPUE "009	Linear growth "010
sdnrs										
sdnrCPUE	1.01	5.05	1.02	1.08	0.89	1.19	1.01	0.99	0.94	1.01
sdnrRDSI	0.96	1.17	2.10	0.96	0.93	1.03	0.96	1.07	1.07	0.96
sdnrCSLF	0.99	1.01	0.99	1.24	0.99	0.93	0.99	1.00	1.00	1.00
sdnrRDLF	1.00	0.98	1.00	0.99	2.66	1.04	1.00	1.00	1.00	1.00
sdnrMaturity	0.99	1.00	0.99	1.02	1.03	1.03	1.34	1.00	1.00	0.95
sdnrPCPUE	0.70	0.46	0.70	0.55	0.83	0.90	0.70	40.08	37.85	0.63
sdnrTags	1.04	1.05	1.04	1.04	1.07	5.06	1.04	1.05	1.05	1.05
Parameters										
$\tilde{\sigma}$	0.201	0.200	0.202	0.196	0.193	0.195	0.201	0.200	0.199	0.210
$\ln(R0)$	14.68	15.56	14.68	14.60	14.47	15.22	14.68	14.63	14.62	15.54
M	0.149	0.299	0.150	0.142	0.131	0.137	0.149	0.144	0.143	0.276
T_{50}	103.63	109.47	103.61	104.00	99.94	111.91	103.63	102.89	102.80	107.48
$T_{95\text{-}50}$	23.85	24.87	23.86	25.60	0.10	21.04	23.85	23.79	23.78	21.27
D_{50}	123.96	124.04	123.96	123.61	123.87	124.17	123.96	123.96	123.95	123.91
$D_{95\text{-}50}$	2.24	2.32	2.24	2.03	2.07	2.67	2.24	2.24	2.24	2.19
L_{50}	90.74	90.74	90.74	90.74	90.74	90.74	89.49	90.74	90.74	90.74
$L_{95\text{-}50}$	11.44	11.44	11.44	11.44	11.44	11.44	17.10	11.44	11.44	11.44
$\ln(q^I)$	-3.49	-11.06	-3.55	-3.36	-2.73	-4.88	-3.49	-2.90	-2.61	-3.08
X	0.192	0.134	0.193	0.190	0.177	0.195	0.192	0.525	0.525	0.193
$\ln(q^J)$	-15.27	-15.28	-13.15	-15.21	-15.32	-15.47	-15.27	-15.26	-15.26	-15.30
g_α	15.91	15.88	15.90	16.13	16.21	5.64	15.91	15.88	15.88	13.75
g_β	5.50	5.77	5.50	5.59	5.74	4.54	5.50	5.48	5.47	5.96
φ	0.592	0.573	0.592	0.585	0.559	0.221	0.592	0.592	0.592	0.566
h	0.643	1.308	0.648	0.633	0.586	0.739	0.643	0.598	0.575	0.608

	Base "001	No CPUE "002	No RDSI "003	No CSLF "004	No RDLF "005	No tags "006	No maturity "007	No PCPUE "008	One CPUE "009	Linear growth "010
Likelihoods										
CPUE	-13.8	1014.4	-13.7	-13.0	-16.7	-10.7	-13.8	-14.3	-19.7	-13.1
PCPUE	-9.7	-12.3	-9.6	-11.6	-7.9	-6.8	-9.7	-19100.2	19748.8	-10.4
RDSI	0.3	1.8	244.3	0.1	-0.1	0.6	0.3	1.0	1.0	0.6
CSLF	-1048.0	-1043.9	-1048.0	-959.5	-1062.1	-1079.7	-1048.0	-1048.7	-1048.4	-1030.5
RDLF	-1100.4	-1109.3	-1100.5	-1111.1	-241.8	-1098.9	-1100.4	-1103.6	-1103.9	-1089.6
Tags	2176.3	2167.9	2176.2	2173.1	2171.0	17171.6	2176.3	2177.2	2177.4	2150.2
Maturity	-30.6	-30.6	-30.6	-30.6	-30.6	-30.6	-21.0	-30.6	-30.6	-30.6
Prior on *M*	0.5	4.8	0.5	0.4	0.2	0.3	0.5	0.4	0.4	4.1
Prior on ε	7.0	11.8	6.9	6.4	7.3	5.1	7.0	6.8	6.8	14.7
U^{max} penalty	0.5	0.4	0.5	0.8	0.3	0.0	0.5	0.4	0.4	0.4
Total likelihood	-18.0	-9.5	-18.3	1014.5	1061.3	-2220.8	12.6	-11.3	-16.5	-4.3
Indicators										
max*Rdev*	1.394	1.478	1.373	1.443	2.077	1.496	1.394	1.282	1.281	1.871
min*Rdev*	0.444	0.397	0.445	0.473	0.495	0.621	0.444	0.457	0.459	0.357
U05	60%	66%	61%	60%	58%	50%	60%	65%	66%	60%
Smin	775	980	776	737	724	1617	774	774	772	910
Sav	1519	2112	1521	1539	1399	2644	1518	1513	1510	2021
S05	1044	1201	1037	1016	912	2074	1043	927	920	1288
Bmin	106	108	106	104	104	149	106	105	105	105
Bav	663	420	662	710	680	736	663	679	683	765
B05	147	131	146	142	155	190	147	131	130	149
S05/Sav	69%	57%	68%	66%	65%	78%	69%	61%	61%	64%
B05/Bav	22%	31%	22%	20%	23%	26%	22%	19%	19%	19%
S05/Smin	135%	123%	134%	138%	126%	128%	135%	120%	119%	142%
B05/Bmin	139%	121%	139%	136%	149%	127%	139%	125%	124%	142%

Table 24: Correlations among estimated parameters in the PAU 7 McMC. Boxes indicate absolute values greater than 0.50.

	ln($R0$)	M	g_α	g_β	T_{50}	T_{95-50}	D_{50}	D_{95-50}	L_{50}	L_{95-50}	φ	$\ln\left(q^I\right)$	X	$\ln\left(q^J\right)$	h
ln($R0$)	1.00														
M	$\boxed{0.92}$	1.00													
g_α	-0.27	-0.15	1.00												
g_β	0.03	0.17	0.30	1.00											
T_{50}	$\boxed{0.72}$	$\boxed{0.73}$	$\boxed{-0.55}$	0.01	1.00										
T_{95-50}	0.17	0.15	-0.07	-0.27	0.40	1.00									
D_{50}	0.31	0.26	-0.28	-0.47	0.25	0.15	1.00								
D_{95-50}	0.16	0.13	-0.07	-0.42	0.10	0.15	$\boxed{0.59}$	1.00							
L_{50}	0.00	-0.01	-0.03	0.00	0.00	0.00	0.02	-0.01	1.00						
L_{95-50}	0.00	0.00	0.00	-0.01	0.00	0.00	0.01	0.00	-0.41	1.00					
φ	0.11	-0.02	$\boxed{-0.53}$	$\boxed{-0.75}$	0.20	0.27	0.35	0.18	0.04	0.01	1.00				
ln(q^I)	0.07	0.02	-0.01	-0.05	0.07	0.03	0.06	0.03	-0.02	-0.02	0.05	1.00			
X	0.05	0.07	-0.02	-0.02	-0.01	-0.01	0.02	0.01	0.02	0.03	0.00	$\boxed{-0.88}$	1.00		
ln(q^J)	-0.05	-0.04	0.00	0.12	0.05	0.06	-0.13	-0.10	0.00	0.01	-0.06	-0.04	0.00	1.00	
h	-0.08	-0.03	0.01	0.07	-0.07	-0.03	-0.06	-0.03	0.02	0.02	-0.06	$\boxed{-1.00}$	$\boxed{0.85}$	0.04	1.00

Table 25: Summary of the marginal posterior distributions from the MCMC chain from the base case for PAU 7. The projected catch is the estimated 2005 catch. The columns show the minimum values observed in the 5000 samples, the maxima, the 5th and 95th percentiles and the medians. The last few rows show the percentage of runs for which the indicator was true. %MPD is the position that the MPD estimate would occupy in the posterior. Biomass is in tonnes.

	min	5%	median	95%	max	%MPD
ln(*R0*)	14.15	14.44	14.68	14.94	15.21	49.4
M	0.111	0.128	0.150	0.177	0.203	46.7
g_α	13.67	14.87	15.76	16.57	18.11	61.3
g_β	4.85	5.22	5.42	5.61	5.87	75.3
T_{50}	100.01	102.09	103.86	105.86	108.42	41.8
$T_{95\text{-}50}$	18.97	22.10	24.43	27.20	32.16	35.1
D_{50}	123.79	123.89	123.98	124.06	124.15	38.2
$D_{95\text{-}50}$	1.93	2.10	2.26	2.43	2.65	42.2
L_{50}	89.02	89.91	90.72	91.49	92.54	51.6
$L_{95\text{-}50}$	8.13	9.83	11.57	13.41	15.74	45.7
φ	0.518	0.575	0.609	0.648	0.709	21.4
ln(q^I)	-5.93	-4.60	-3.48	-2.38	-1.23	49.3
X	0.159	0.174	0.192	0.213	0.240	49.9
ln(q^J)	-15.65	-15.44	-15.28	-15.12	-14.94	52.3
h	0.468	0.558	0.642	0.729	0.832	51.2
sdnrCPUE	0.813	0.921	1.044	1.209	1.470	34.9
sdnrCPUE2	0.334	0.570	0.760	0.978	1.290	30.1
sdnrRDSI	0.815	0.892	0.966	1.040	1.142	44.1
sdnrCSLF	0.955	0.979	0.998	1.019	1.044	25.0
sdnrRDLF	0.961	0.990	1.016	1.046	1.082	19.5
sdnrTags	0.947	0.989	1.029	1.070	1.126	74.0
*sdnr*Maturity	0.987	0.989	1.013	1.088	1.219	11.0
U05	55%	58%	60%	62%	65%	55.9
U08	26%	30%	33%	38%	44%	42.4
Smin	704	745	786	843	910	34.0
Sav	1334	1447	1546	1681	1854	34.8
S05	889	970	1058	1165	1322	40.3
S06	927	1039	1162	1310	1511	54.4
S07	925	1073	1233	1438	1855	44.4
S08	894	1086	1285	1547	2136	26.0
Bmin	98	103	106	110	117	37.8
Bav	500	589	673	765	862	42.9
B05	132	140	148	157	169	43.9
B06	163	180	194	212	235	48.5
B07	203	232	261	294	338	51.5
B08	245	299	348	403	471	56.4
S05/Sav	58%	64%	68%	73%	81%	55.6
S05/Smin	114%	126%	134%	145%	158%	52.6
S08/Sav	57%	70%	83%	99%	133%	33.2
S08/S05	91%	106%	121%	141%	178%	27.4
B05/Bav	16%	19%	22%	25%	30%	54.3
B05/Bmin	121%	131%	139%	148%	158%	52.9
B08/Bav	34%	43%	52%	62%	82%	60.4
B08/B05	172%	208%	235%	265%	302%	61.4
S08<S05	1.0%	*B08<B05*	0.0%	*S08<Smin*	0.0%	
S08<Sav	95.4%	*B08<Bav*	100.0%	*B08<Bmin*	0.0%	

Table 26: Comparison of the posterior distributions for parameters and two indicators between the 2005 and 2003 assessments. Only those variables common to the two assessments are shown.

			2005			2003
	5%	Median	95%	5%	Median	95%
ln(R0)	14.44	14.68	14.94	14.09	14.33	14.58
M	0.128	0.150	0.177	0.104	0.123	0.145
g_α	14.87	15.76	16.57	15.28	16.04	16.84
g_β	5.22	5.42	5.61	5.26	5.46	5.65
T_{50}	102.09	103.86	105.86	101.9	104.32	107.13
T_{95-50}	22.10	24.43	27.20	27.95	31.76	36.51
D_{50}	123.89	123.98	124.06	123.69	123.78	123.87
D_{95-50}	2.10	2.26	2.43	2.35	2.56	2.76
L_{50}	89.91	90.72	91.49	86.35	88.26	89.83
L_{95-50}	9.83	11.57	13.41	12.27	16.11	21.45
φ	0.575	0.609	0.648	0.56	0.59	0.62
ln(q^J)	-15.44	-15.28	-15.12	-15.24	-15.06	-14.87
h	0.558	0.642	0.729	0.55	0.624	0.704
Sav	1447	1546	1681	1339	1412	1502
Bav	589	673	765	580	664	753

Table 27: Summary of parameter estimates and indicators from the retrospective McMC sensitivity trials. Biomass indicators are in tonnes.

Trial	Base 5%	Base Median	Base 95%	2004 5%	2004 Median	2004 95%	2003 5%	2003 Median	2003 95%	2002 5%	2002 Median	2002 95%	2001 5%	2001 Median	2001 95%
ln($R0$)	14.44	14.68	14.94	14.33	14.56	14.79	14.31	14.52	14.74	14.30	14.63	14.97	14.47	14.84	15.23
M	0.128	0.150	0.177	0.118	0.137	0.157	0.116	0.133	0.152	0.118	0.152	0.190	0.138	0.185	0.237
g_α	14.87	15.76	16.57	15.05	15.92	16.80	15.09	15.90	16.71	15.07	15.82	16.59	14.85	15.55	16.31
g_β	5.22	5.42	5.61	5.22	5.42	5.61	5.17	5.37	5.56	5.46	5.70	5.95	5.92	6.22	6.52
T_{50}	102.09	103.86	105.86	100.91	102.93	104.95	100.63	102.51	104.48	101.25	103.72	106.46	103.99	106.70	109.24
$T_{95\text{-}50}$	22.10	24.43	27.20	22.34	25.19	28.54	22.60	25.62	29.03	21.74	24.66	28.36	21.53	24.09	27.07
D_{50}	123.89	123.98	124.06	123.86	123.95	124.04	123.78	123.86	123.96	123.75	123.84	123.94	123.78	123.89	123.99
$D_{95\text{-}50}$	2.10	2.26	2.43	2.10	2.29	2.47	2.07	2.26	2.45	2.11	2.32	2.55	2.34	2.59	2.85
L_{50}	89.91	90.72	91.49	89.87	90.68	91.46	89.95	90.73	91.45	89.94	90.70	91.45	89.91	90.70	91.41
$L_{95\text{-}50}$	9.83	11.57	13.41	9.88	11.61	13.50	9.82	11.52	13.46	9.92	11.57	13.39	9.92	11.53	13.38
φ	0.575	0.609	0.648	0.564	0.597	0.634	0.570	0.602	0.639	0.551	0.583	0.620	0.540	0.572	0.605
ln(q^J)	-4.60	-3.48	-2.38	-3.99	-2.82	-1.65	-4.01	-2.88	-1.78	-4.27	-3.13	-2.00	-5.37	-3.88	-2.53
X	0.174	0.192	0.213	0.163	0.181	0.202	0.165	0.182	0.202	0.160	0.181	0.204	0.200	0.200	0.200
ln(q^J)	-15.44	-15.28	-15.12	-15.48	-15.31	-15.14	-15.48	-15.31	-15.14	-15.53	-15.35	-15.16	-15.51	-15.32	-15.14
h	0.558	0.642	0.729	0.502	0.591	0.682	0.511	0.596	0.684	0.529	0.617	0.705	0.574	0.679	0.796
sdnrCPUE	0.921	1.044	1.209	0.897	1.019	1.170	0.931	1.050	1.199	0.939	1.077	1.247	1.025	1.154	1.320
sdnrPCPUE	0.570	0.760	0.978	0.588	0.739	0.913	0.224	0.468	0.714	0.015	0.150	0.445	0.000	0.000	0.000
sdnrRDSI	0.892	0.966	1.040	0.911	1.001	1.101	0.946	1.043	1.147	0.821	0.945	1.083	0.924	1.081	1.265
sdnrCSLF	0.979	0.998	1.019	0.955	1.006	1.059	0.944	0.997	1.054	0.934	0.989	1.047	0.927	0.983	1.044
sdnrRDLF	0.990	1.016	1.046	0.908	0.961	1.013	0.917	0.972	1.027	0.921	0.983	1.044	0.918	0.978	1.042
sdnrTags	0.989	1.029	1.070	1.005	1.045	1.086	1.002	1.041	1.081	0.998	1.039	1.080	0.979	1.019	1.062
*sdnr*Maturity	0.989	1.013	1.088	0.969	1.029	1.119	0.985	1.047	1.134	1.008	1.073	1.159	1.019	1.087	1.175
Smin	745	786	843	728	769	821	720	756	800	684	760	842	778	870	967
Sav	1447	1546	1681	1411	1500	1613	1413	1496	1597	1349	1454	1602	1264	1396	1583
Bmin	103	106	110	103	106	110	103	107	111	99	107	114	118	129	141
Bav	589	673	765	603	685	772	598	683	768	557	647	735	495	581	678

Table 28: Summary of parameter estimates and indicators from the McMC sensitivity trials in which maximum exploitation rate was varied to values indicated. Projected catches are the estimated 2005 catch. "*f*" indicates the function value. Biomass indicators are in tonnes.

Trial	65% 5%	65% Median	65% 95%	Base 5%	Base Median	Base 95%	90% 5%	90% Median	90% 95%
f	42.5	49.6	58.7	-2.6	3.3	11.0	-15.6	-9.6	-1.9
$\ln(R0)$	15.76	16.24	16.71	14.44	14.68	14.94	14.39	14.61	14.84
M	0.307	0.390	0.473	0.128	0.150	0.177	0.129	0.145	0.163
g_α	15.51	16.32	17.18	14.87	15.76	16.57	14.42	15.33	16.32
g_β	5.07	5.36	5.65	5.22	5.42	5.61	5.51	5.75	5.98
T_{50}	109.14	112.20	114.58	102.09	103.86	105.86	102.71	104.49	106.32
$T_{95\text{-}50}$	22.35	24.17	26.37	22.10	24.43	27.20	22.36	24.75	27.44
D_{50}	123.95	124.04	124.12	123.89	123.98	124.06	123.94	124.03	124.12
$D_{95\text{-}50}$	2.11	2.27	2.43	2.10	2.26	2.43	2.17	2.35	2.53
L_{50}	89.90	90.71	91.45	89.91	90.72	91.49	89.91	90.71	91.47
$L_{95\text{-}50}$	9.84	11.52	13.51	9.83	11.57	13.41	9.83	11.59	13.48
φ	0.552	0.587	0.627	0.575	0.609	0.648	0.567	0.603	0.644
$\ln(q^I)$	-4.10	-2.86	-1.81	-4.60	-3.48	-2.38	-4.16	-3.08	-2.03
X	0.171	0.188	0.207	0.174	0.192	0.213	0.176	0.195	0.217
$\ln(q^J)$	-15.69	-15.53	-15.37	-15.44	-15.28	-15.12	-15.34	-15.17	-15.00
h	0.495	0.577	0.671	0.558	0.642	0.729	0.535	0.616	0.700
sdnrCPUE	1.061	1.215	1.409	0.921	1.044	1.209	0.880	0.999	1.160
sdnrPCPUE	0.686	0.895	1.112	0.570	0.760	0.978	0.470	0.679	0.906
sdnrRDSI	0.954	1.036	1.124	0.892	0.966	1.040	0.906	0.980	1.053
sdnrCSLF	0.969	0.993	1.018	0.979	0.998	1.019	0.999	1.018	1.039
sdnrRDLF	1.024	1.052	1.083	0.990	1.016	1.046	0.981	1.006	1.035
sdnrTags	1.021	1.060	1.100	0.989	1.029	1.070	0.974	1.013	1.055
sdnrMaturityt	0.989	1.012	1.091	0.989	1.013	1.088	0.989	1.012	1.089
U05	45%	47%	49%	58%	60%	62%	64%	67%	70%
U08	25%	29%	32%	30%	33%	38%	32%	36%	41%
Smin	1174	1352	1563	745	786	843	681	724	779
Sav	2794	3588	4677	1447	1546	1681	1319	1414	1535
S05	1688	2059	2538	970	1058	1165	876	963	1064
S06	1778	2187	2798	1039	1162	1310	944	1062	1201
S07	1729	2178	2877	1073	1233	1438	976	1132	1323
S08	1636	2131	2904	1086	1285	1547	993	1186	1435
Bmin	145	149	154	103	106	110	85	90	96
Bav	896	1088	1348	589	673	765	549	628	712
B05	194	206	221	140	148	157	120	128	138
B06	237	256	282	180	194	212	158	173	190
B07	288	322	363	232	261	294	209	238	271
B08	348	403	470	299	348	403	275	323	378
S05/Sav	51%	58%	65%	64%	68%	73%	63%	68%	73%
S05/Smin	139%	152%	169%	126%	134%	145%	124%	133%	142%
S08/Sav	45%	60%	78%	70%	83%	99%	71%	84%	100%
S08/S05	82%	104%	132%	106%	121%	141%	107%	123%	143%
B05/Bav	15%	19%	23%	19%	22%	25%	18%	20%	23%
B05/Bmin	130%	138%	147%	131%	139%	148%	133%	142%	153%
B08/Bav	29%	37%	46%	43%	52%	62%	42%	51%	62%
B08/B05	173%	196%	221%	208%	235%	265%	219%	252%	288%
S08<S05	39.0%			1.0%			0.5%		
S08<Sav	99.9%			95.4%			94.7%		

Table 29: Comparison of the “implicit prior McMC sensitivity trial with the base case.

	Base 5%	Base Median	Base 95%	Implicit 5%	Implicit Median	Implicit 95%
$\ln(R0)$	14.44	14.68	14.94	15.76	31.67	48.18
M	0.128	0.150	0.177	0.063	0.112	0.199
g_α	14.87	15.76	16.57	3.48	25.49	47.11
g_β	5.22	5.42	5.61	2.51	25.37	47.54
T_{50}	102.09	103.86	105.86	72.59	98.19	122.01
$T_{95\text{-}50}$	22.10	24.43	27.20	2.83	25.53	47.29
D_{50}	123.89	123.98	124.06	73.92	108.49	141.12
$D_{95\text{-}50}$	2.10	2.26	2.43	2.34	25.02	47.30
L_{50}	89.91	90.72	91.49	74.07	108.13	141.50
$L_{95\text{-}50}$	9.83	11.57	13.41	3.69	25.80	47.26
φ	0.575	0.609	0.648	0.058	0.505	0.950
$\ln(q^I)$	-4.60	-3.48	-2.38	-28.52	-15.08	-1.53
X	0.174	0.192	0.213	0.103	0.526	0.952
$\ln(q^J)$	-15.44	-15.28	-15.12	-28.39	-14.94	-1.62
h	0.558	0.642	0.729	0.117	1.028	1.895
sdnrCPUE	0.921	1.044	1.209	1.320	13.249	126.684
sdnrCPUE2	0.570	0.760	0.978	20.135	289.868	2780.085
sdnrRDSI	0.892	0.966	1.040	0.670	5.815	51.049
sdnrCSLF	0.979	0.998	1.019	1.905	4.851	42.256
sdnrRDLF	0.990	1.016	1.046	1.954	7.542	63.993
sdnrTags	0.989	1.029	1.070	0.234	0.898	6.229
*sdnr*Maturity	0.989	1.013	1.088	0.624	2.252	19.811
U05	58%	60%	62%	0.00%	0.00%	0.81%
U08	30%	33%	38%	0.00%	0.00%	0.81%
Smin	745	786	843	20713	1.82E+11	2.52E+18
Sav	1447	1546	1681	22601	1.94E+11	2.81E+18
S05	970	1058	1165	21885	2.07E+11	2.74E+18
S06	1039	1162	1310	21465	2.07E+11	2.76E+18
S07	1073	1233	1438	21241	2.06E+11	2.78E+18
S08	1086	1285	1547	21519	2.06E+11	2.75E+18
Bmin	103	106	110	19546	1.73E+11	2.51E+18
Bav	589	673	765	21322	1.89E+11	2.81E+18
B05	140	148	157	20909	1.93E+11	2.75E+18
B06	180	194	212	21127	1.94E+11	2.73E+18
B07	232	261	294	21050	1.97E+11	2.72E+18
B08	299	348	403	20757	1.96E+11	2.77E+18
S05/Sav	64%	68%	73%	82%	100%	122%
S05/Smin	126%	134%	145%	100%	108%	131%
S08/Sav	70%	83%	99%	81%	100%	125%
S08/S05	106%	121%	141%	92%	100%	110%
B05/Bav	19%	22%	25%	82%	100%	122%
B05/Bmin	131%	139%	148%	100%	109%	132%
B08/Bav	43%	52%	62%	81%	100%	125%
B08/B05	208%	235%	265%	92%	100%	111%
S08<S05	1.0%			51.4%		
S08<Sav	95.4%			49.3%		
B08<B05	0.0%			51.2%		
B08<Bav	100.0%			49.3%		
S08<Smin	0.0%			16.9%		
B08<Bmin	0.0%			15.8%		

Table 30: Summary of results from projections using alternative catches (Table 3). For all but the last two columns these are the MEDIANS of projections; the last four columns show the percentage of runs for which the indicator was true. In no run was biomass less than *Smin* or *Bmin*.

	U08	*S06*	*S07*	*S08*	*B06*	*B07*	*B08*	*S08/ Sav*	*S08/ S05*	*B08/ Bav*	*B08/ B05*	*%S08 <S05*	*%S08 <Sav*	*%B08 <B05*	*%B08 <Bav*
0%	0.518	1136	1159	1167	175	197	241	0.75	1.10	0.36	1.63	15.5	98.8	0.0	100.0
5%	0.476	1141	1172	1190	178	209	261	0.77	1.13	0.39	1.77	10.5	98.5	0.0	100.0
10%	0.437	1145	1186	1212	182	220	281	0.78	1.15	0.42	1.90	6.6	97.9	0.0	100.0
15%	0.401	1150	1200	1234	186	232	301	0.80	1.17	0.45	2.04	4.0	97.5	0.0	100.0
20%	0.368	1155	1214	1257	189	244	321	0.81	1.19	0.48	2.17	2.2	96.8	0.0	100.0
25%	0.337	1159	1227	1279	193	256	342	0.83	1.21	0.51	2.31	1.2	95.8	0.0	100.0
30%	0.308	1164	1241	1301	196	268	362	0.84	1.23	0.54	2.45	0.6	94.6	0.0	100.0
35%	0.281	1169	1254	1323	200	280	383	0.85	1.25	0.57	2.59	0.2	92.9	0.0	100.0
40%	0.255	1173	1268	1346	203	292	403	0.87	1.27	0.60	2.73	0.1	91.1	0.0	100.0
45%	0.231	1178	1282	1368	207	304	424	0.88	1.29	0.63	2.87	0.0	88.9	0.0	100.0
50%	0.209	1183	1296	1390	210	316	445	0.90	1.31	0.66	3.01	0.0	86.0	0.0	100.0
55%	0.187	1187	1309	1413	214	329	466	0.91	1.33	0.69	3.15	0.0	83.2	0.0	100.0
60%	0.167	1192	1323	1435	217	341	487	0.93	1.36	0.72	3.29	0.0	79.3	0.0	100.0
65%	0.148	1197	1337	1457	221	353	508	0.94	1.38	0.75	3.43	0.0	74.4	0.0	99.7
70%	0.130	1201	1350	1480	225	366	529	0.95	1.40	0.79	3.57	0.0	69.4	0.0	99.3
75%	0.113	1206	1364	1502	228	378	550	0.97	1.42	0.82	3.71	0.0	63.1	0.0	98.4
80%	0.097	1211	1378	1524	232	390	571	0.98	1.44	0.85	3.85	0.0	57.4	0.0	96.1
85%	0.082	1215	1392	1546	235	403	592	1.00	1.46	0.88	4.00	0.0	51.3	0.0	91.6
90%	0.067	1220	1405	1568	239	415	613	1.01	1.48	0.91	4.14	0.0	44.4	0.0	84.0
95%	0.053	1225	1419	1590	242	428	634	1.03	1.50	0.94	4.28	0.0	38.0	0.0	73.9
100%	0.040	1229	1433	1613	246	440	655	1.04	1.52	0.97	4.43	0.0	31.4	0.0	61.3

Table 31: Summary of results from projections using alternative catches (Table 3). These are the 5th quantiles of projections.

	U08	S06	S07	S08	B06	B07	B08	S08/ Sav	S08/ S05	B08/ Bav	B08/ B05
0%	0.448	1014	998	969	160	169	194	0.626	0.945	0.283	1.349
5%	0.414	1018	1012	991	164	180	214	0.641	0.966	0.310	1.486
10%	0.382	1023	1026	1013	167	192	233	0.655	0.987	0.338	1.623
15%	0.352	1028	1040	1035	171	203	253	0.669	1.008	0.365	1.760
20%	0.324	1032	1053	1057	174	215	273	0.684	1.029	0.393	1.897
25%	0.298	1037	1067	1080	178	227	293	0.698	1.051	0.421	2.037
30%	0.273	1042	1081	1102	181	239	314	0.711	1.072	0.449	2.175
35%	0.250	1046	1095	1124	185	251	334	0.725	1.094	0.476	2.314
40%	0.228	1051	1108	1146	189	263	355	0.739	1.114	0.504	2.455
45%	0.207	1056	1122	1169	192	275	375	0.753	1.136	0.532	2.596
50%	0.188	1060	1136	1191	196	287	396	0.767	1.156	0.560	2.736
55%	0.169	1065	1150	1213	199	299	417	0.781	1.177	0.588	2.877
60%	0.151	1070	1163	1236	203	312	437	0.795	1.198	0.617	3.018
65%	0.135	1074	1177	1258	206	324	458	0.809	1.218	0.645	3.159
70%	0.119	1079	1191	1280	210	336	479	0.823	1.239	0.673	3.301
75%	0.103	1084	1205	1303	213	349	500	0.837	1.260	0.700	3.443
80%	0.089	1088	1218	1325	217	361	521	0.851	1.280	0.728	3.585
85%	0.075	1093	1232	1348	220	373	542	0.865	1.300	0.756	3.725
90%	0.062	1098	1246	1370	224	386	563	0.879	1.321	0.784	3.865
95%	0.049	1102	1260	1393	227	398	584	0.893	1.341	0.812	4.005
100%	0.037	1107	1273	1415	231	411	605	0.906	1.361	0.840	4.147

Table 32: Summary of results from projections using alternative catches (Table 3). These are the 95th quantiles of projections.

	U08	S06	S07	S08	B06	B07	B08	S08/ Sav	S08/ S05	B08/ Bav	B08/ B05
0%	0.601	1285	1365	1428	192	230	296	0.917	1.303	0.450	1.942
5%	0.548	1289	1379	1450	196	242	316	0.931	1.324	0.482	2.075
10%	0.501	1294	1392	1473	199	253	336	0.946	1.344	0.514	2.206
15%	0.457	1299	1406	1496	203	265	356	0.960	1.366	0.546	2.342
20%	0.417	1303	1419	1519	206	277	377	0.974	1.387	0.579	2.478
25%	0.380	1308	1433	1541	210	289	397	0.989	1.408	0.612	2.611
30%	0.346	1313	1447	1563	214	301	418	1.004	1.429	0.646	2.747
35%	0.314	1317	1460	1586	217	313	438	1.018	1.450	0.679	2.883
40%	0.285	1322	1474	1608	221	326	459	1.033	1.471	0.713	3.022
45%	0.257	1327	1488	1630	224	338	480	1.047	1.492	0.747	3.162
50%	0.231	1331	1501	1652	228	350	501	1.062	1.514	0.781	3.303
55%	0.207	1336	1515	1674	231	362	522	1.077	1.534	0.815	3.441
60%	0.185	1341	1529	1696	235	374	543	1.092	1.555	0.849	3.581
65%	0.163	1345	1542	1718	238	387	564	1.106	1.576	0.884	3.722
70%	0.143	1350	1556	1740	242	399	585	1.122	1.597	0.920	3.865
75%	0.124	1355	1569	1762	246	411	606	1.137	1.618	0.955	4.007
80%	0.106	1359	1583	1784	249	424	627	1.151	1.638	0.989	4.149
85%	0.089	1364	1596	1807	253	436	649	1.167	1.659	1.025	4.296
90%	0.073	1369	1610	1829	256	449	670	1.181	1.680	1.059	4.444
95%	0.058	1373	1624	1851	260	461	691	1.196	1.701	1.094	4.590
100%	0.043	1378	1637	1873	263	474	713	1.211	1.723	1.129	4.735

Table 33: Catch and raw CPUE (kg per diver day) from CELRs for statistical areas 18 and 36.

Stat area	18	18	18	36	36	36	18 & 36	18 & 36	18 & 36
Fishing year	Catch (kg)	Diver days	CPUE	Catch (kg)	Diver days	CPUE	Catch (kg)	Diver days	CPUE
1983				350	2	175.0	350	2	175.0
1984				3150	22	143.2	3150	22	143.2
1986				620	1	620.0	620	1	620.0
1987				2139	3	713.0	2139	3	713.0
1988				703	1	703.0	703	1	703.0
1989				250	3	83.3	250	3	83.3
1990				435	4	108.8	435	4	108.8
1991	1873	10	187.3	1833	10	183.3	3706	20	185.3
1992	1804	23	78.4	15463	89	173.7	17267	112	154.2
1993	2688	23	116.9	6170	34	181.5	8858	57	155.4
1994	6214	53	117.2	1010	8	126.3	7224	61	118.4
1995	5269	57	92.4	4601	42	109.5	9870	99	99.7
1996	8945	78	114.7	15575	80	194.7	24520	158	155.2
1997	16844	151	111.5	17000	96	177.1	33844	247	137.0
1998	40808	312	130.8	2110	15	140.7	42918	327	131.2
1999	22068	196	112.6	9075	56	162.1	31143	252	123.6
2000	67140	478	140.5	6094	37	164.7	73234	515	142.2
2001	78183	654	119.5	12309	116	106.1	90492	770	117.5
2002	650	6	108.3				650	6	108.3

Table 34: Catch and raw PCPUE (kg per diver hour) from PCELRs for statistical areas 18 and 36.

Fishing year	18 Catch (kg)	18 Diver hours	18 PCPUE	36 Catch (kg)	36 Diver hours	36 PCPUE	Total Catch (kg)	Total Diver hours	Total PCPUE
2002	40954	2107	19.4	5417	289	18.7	46371	2396	19.4
2003	19665	1318	14.9	1662	106	15.7	21327	1424	15.0
2004	13811	1006	13.7	95	2	40.7	13906	1009	13.8
2005	8668	498	17.4	1410	37	38.6	10078	535	18.9

Table 35: Number of research diver survey timed swims and average abundance (number per 10 minutes) in statistical areas 18 and 36, by fishing year.

Area	No. of swims		Mean abundance	
Year	18	36	18	36
2003	22	18	7.0	46.3
2005	2	0	5.0	–

Table 36: Number of paua collected in research diver surveys in area 18 and 36.

	Area		
Year	18	36	Total
2003	170	294	464
2005	10		26
Total	180	294	490

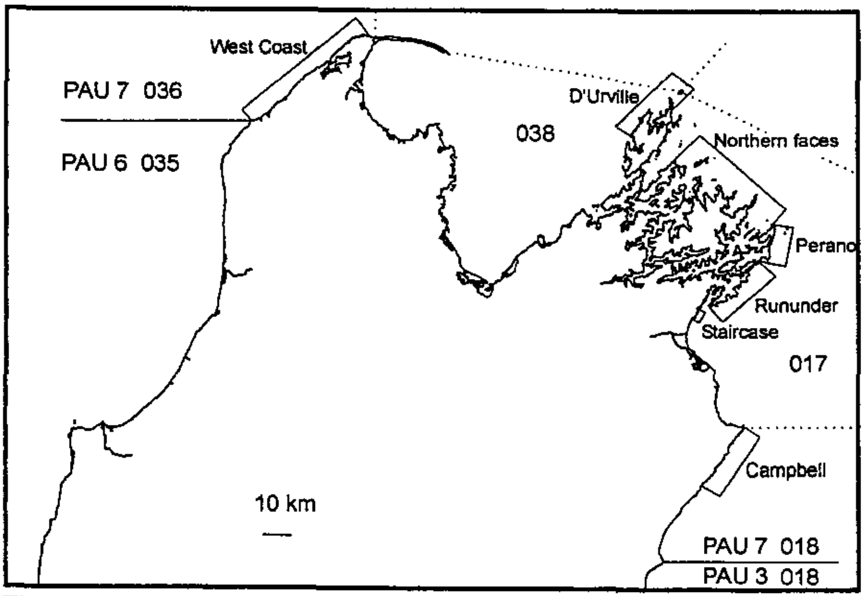


Figure 1: Boundaries of PAU 7, statistical areas and research survey strata.

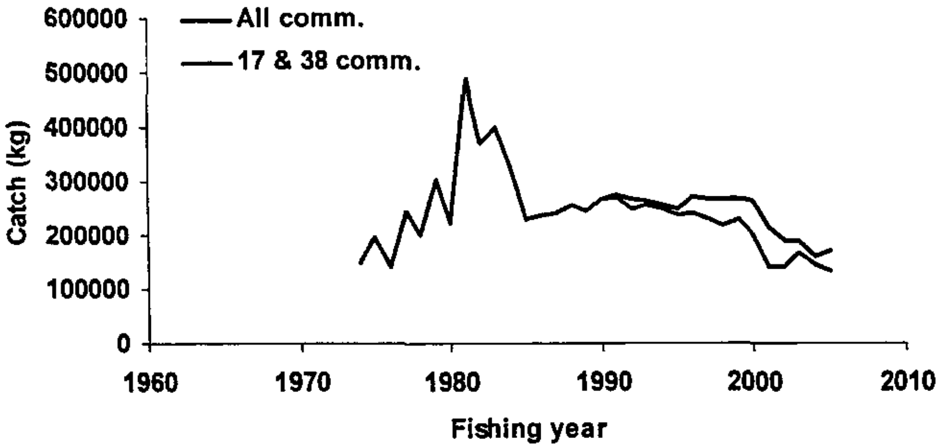


Figure 2: Estimated commercial catch (kg) in PAU 7 as a whole (upper black line) and from statistical areas 17 and 38 only (lower grey line). All of the commercial catch is assumed to be from areas 18 and 38 before 1989.

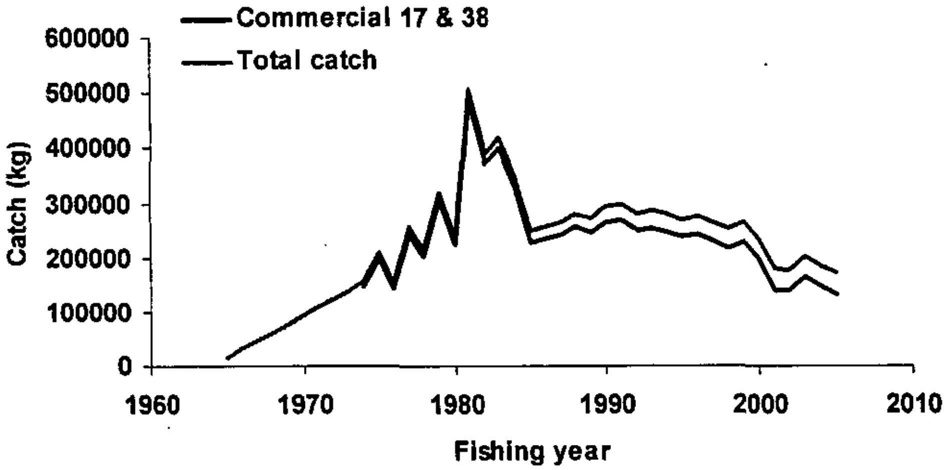


Figure 3: Trajectories of the stock assessment's estimated total catch, including commercial and non-commercial catches (upper line) and commercial catch (lower, black line) trajectories for areas 17 and 38 only.

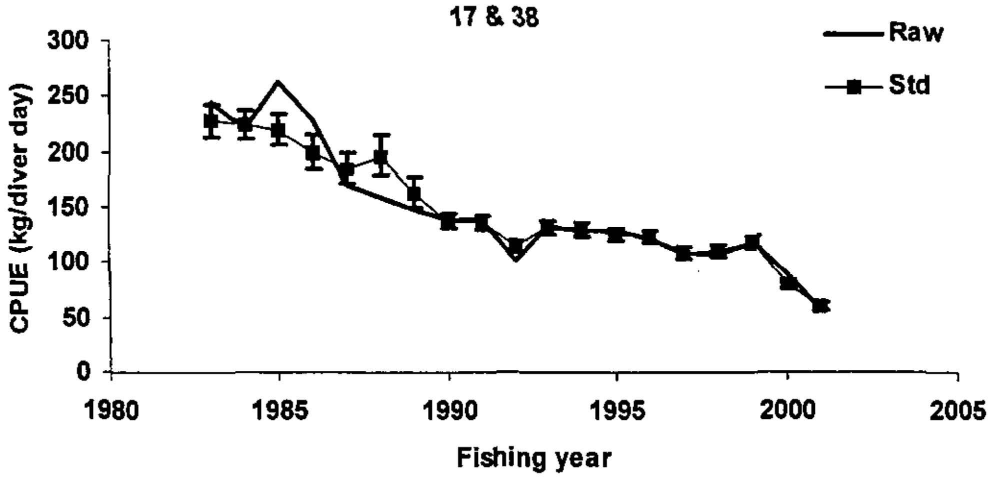


Figure 4: Standardised (grey line) and raw (black line) CPUE (kg/diver day) from areas 17 and 38 combined, taken from CELR data. Vertical bars show the 95% confidence intervals.

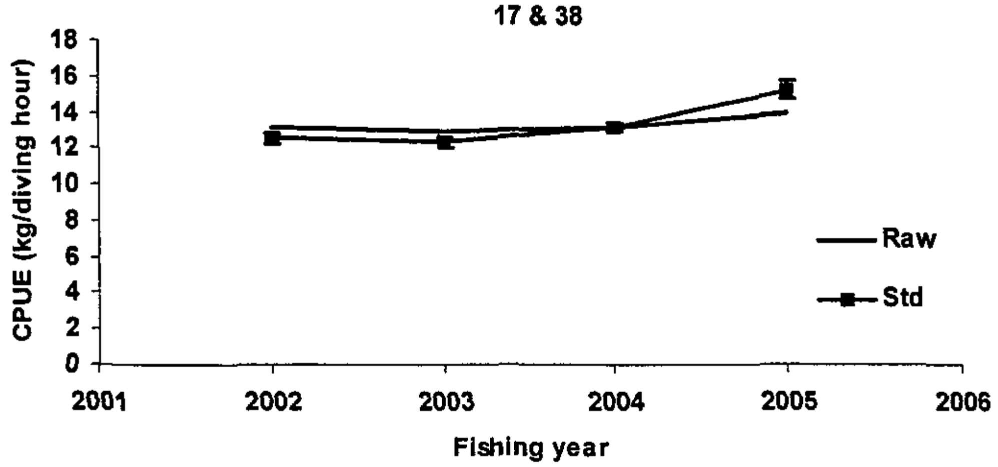


Figure 5: Standardised (grey line) and raw (black line) PCPUE (kg/diver hour) from areas 17 and 38 combined, taken from PCELR data. Vertical bars show the 95% confidence intervals.

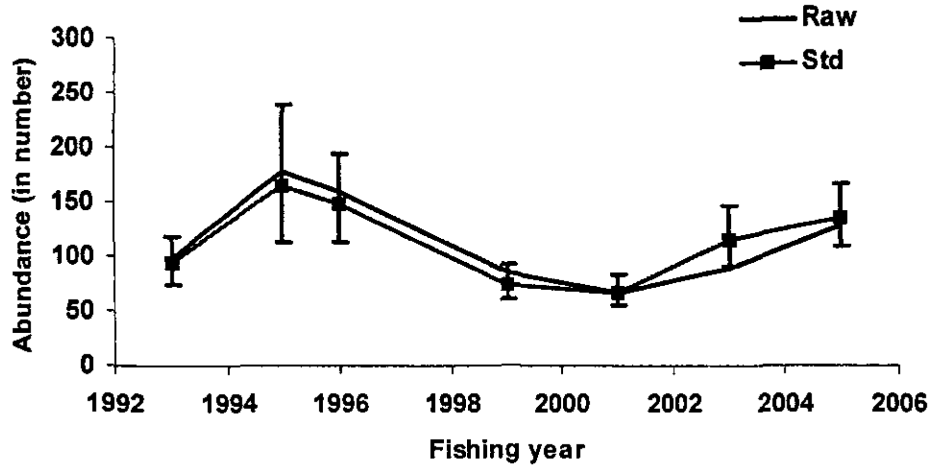


***Figure 6**: Raw (black line) and standardised (grey line) RDSI from areas 17 and 38 combined. Vertical bars show the 95% confidence intervals.*

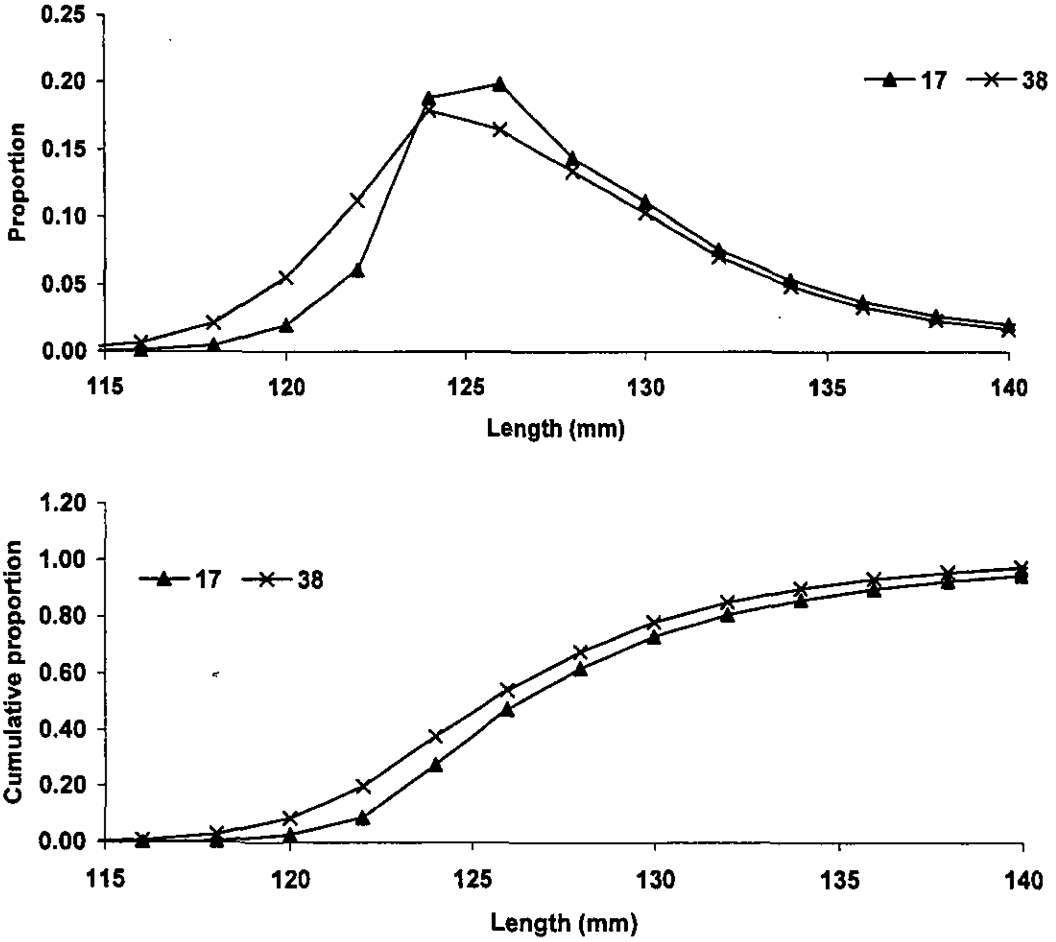


Figure 7: CSLFs from statistical areas 17 and 38, combined from all years, plotted as proportion-at-length (top) and cumulative proportion-at-length (bottom).

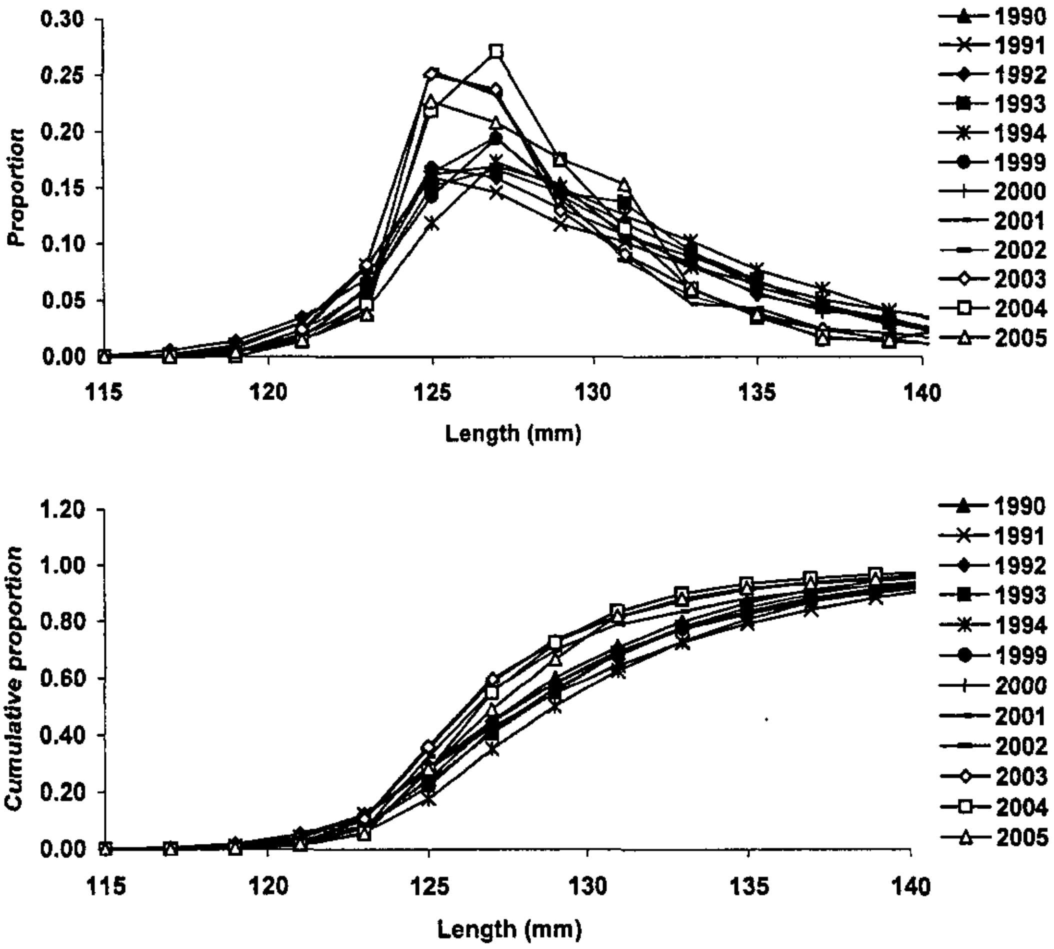


Figure 8: CSLFs from statistical areas 17 and 38 combined, plotted as proportion-at-length (top) and cumulative proportion-at-length (bottom) for each year.

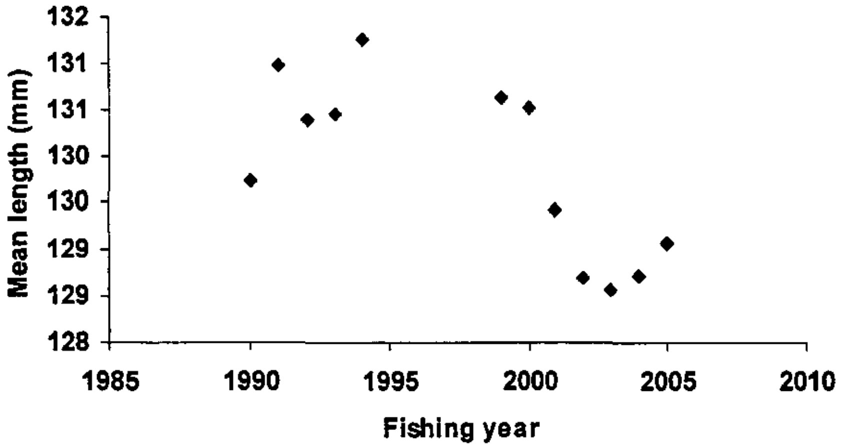
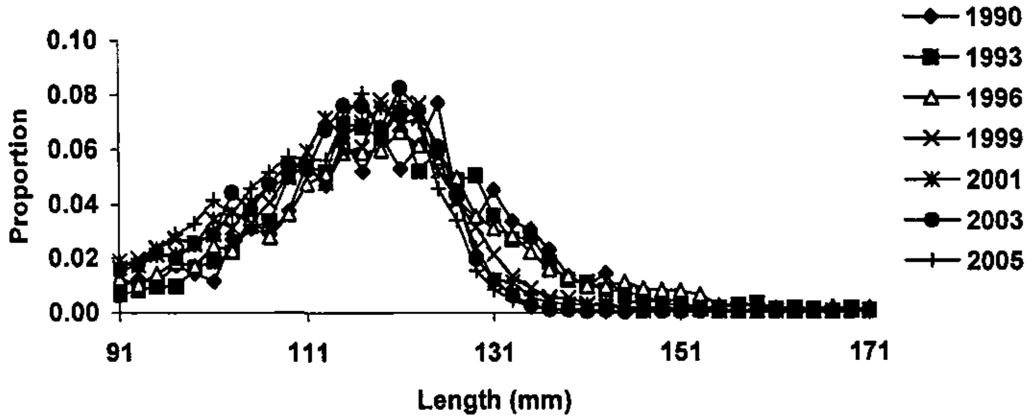


Figure 9: Mean length of paua in the CSLF dataset.



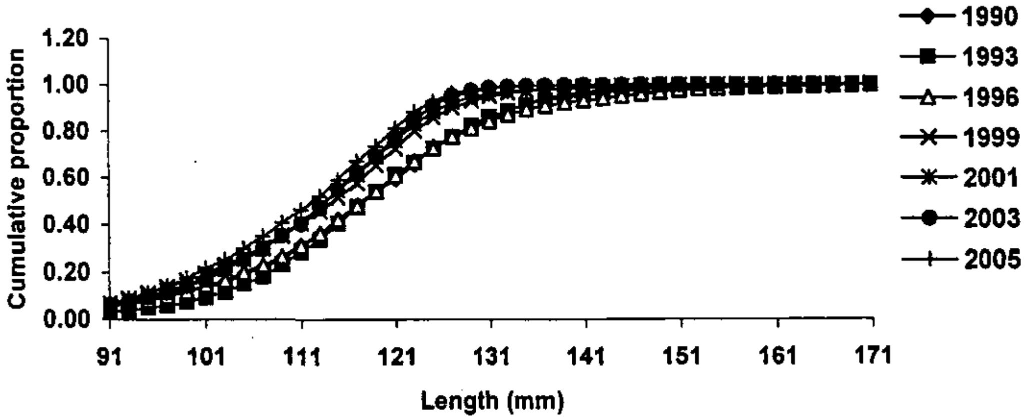
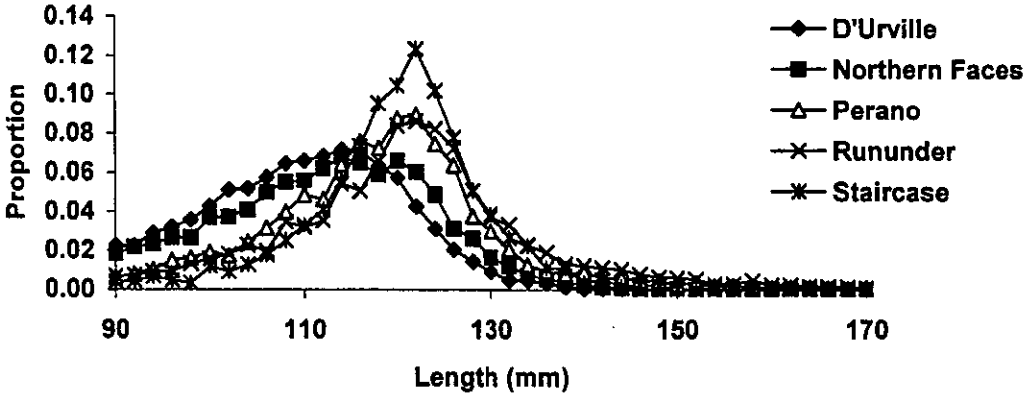


Figure 10: RDLFs from all survey strata within areas 17 and 38 aggregated for each year and plotted as proportion-at-length (top) and cumulative proportion-at-length (bottom) for each year.



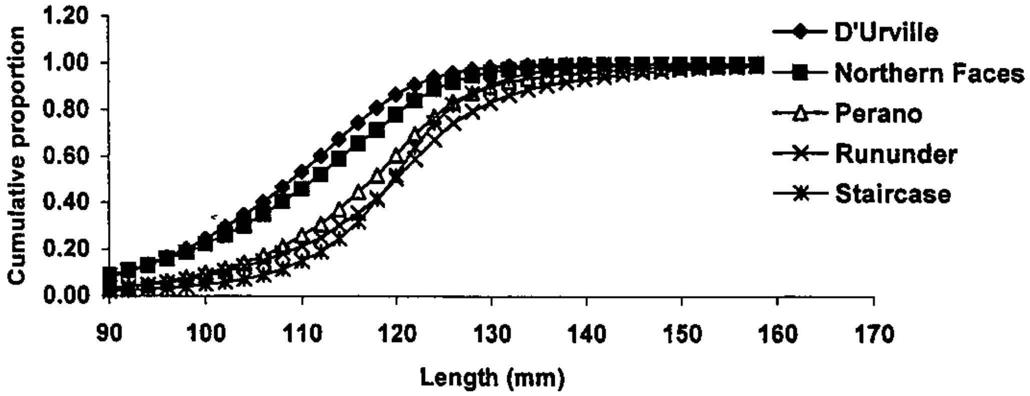


Figure 11: RDLFs from all years combined, plotted as proportion-at-length (top) and cumulative proportion-at-length (bottom) for each survey stratum.

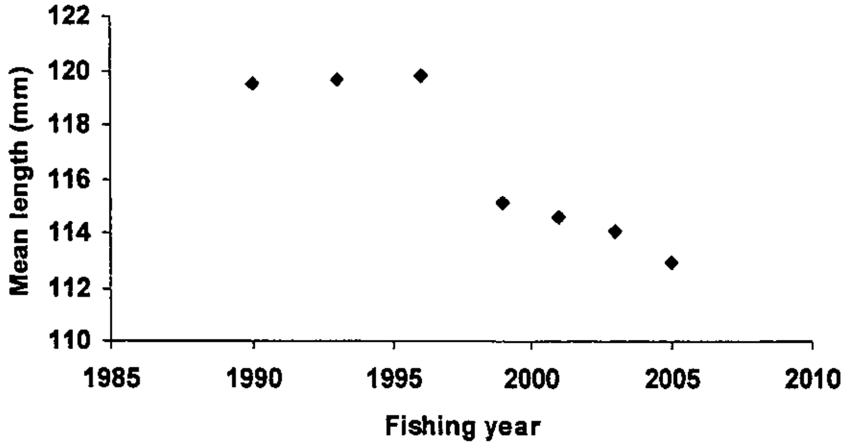


Figure 12: Mean length of paua in the RDLF dataset.

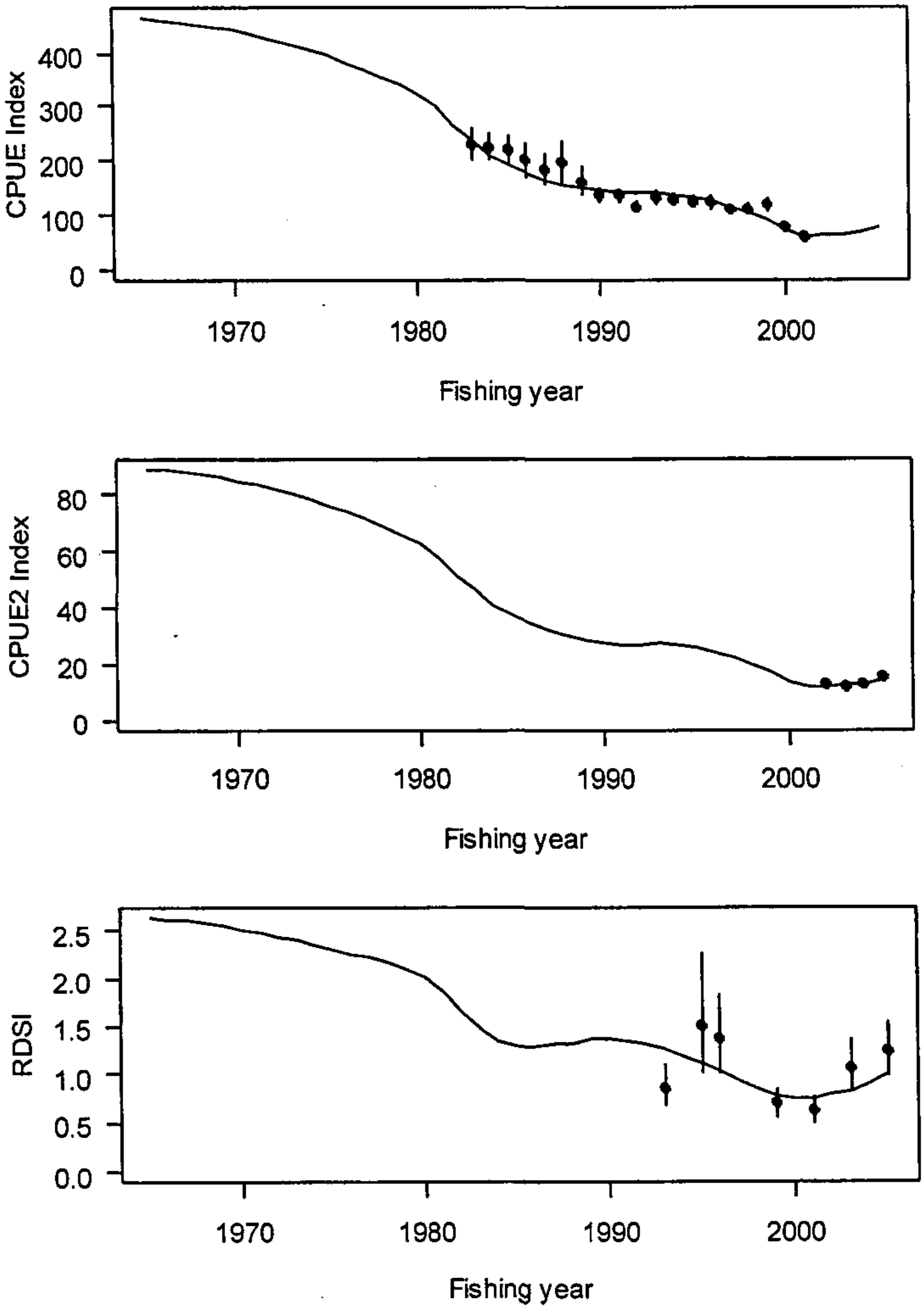


Figure 13: Observed (dots) and predicted (solid line) CPUE (top), PCPUE (middle) and RDSI (bottom) for the base case MPD fit for PAU 7. Error bars show the standard error term used by the model in fitting, including the effects of the common error term and the dataset weights.

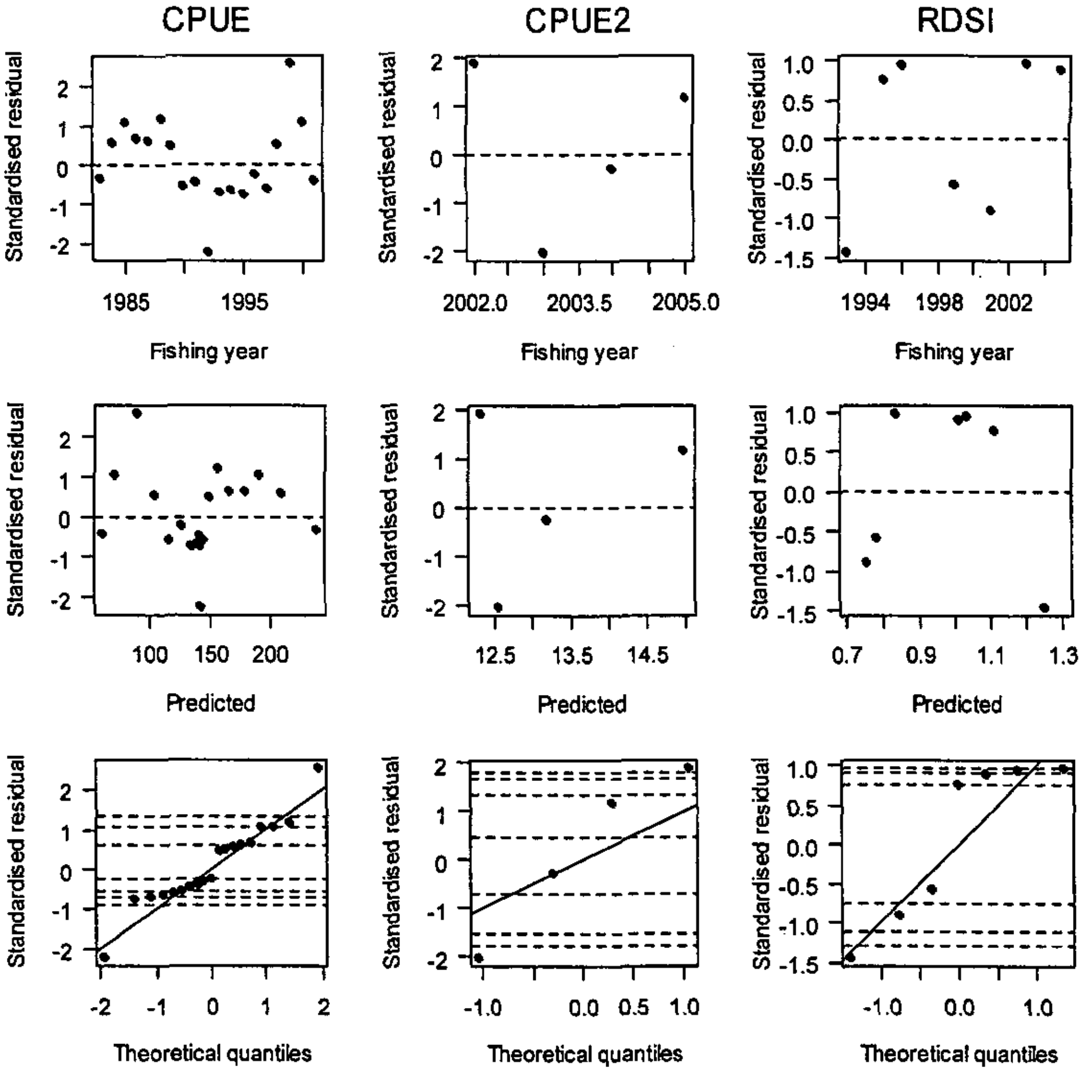


Figure 14: Normalised residuals for CPUE (left), PCPUE (middle) and RDSI (right) for the base case MPD fit for PAU 7. The horizontal lines in bottom plots are 5, 10, 25, 50, 75, 90, 95th percentiles.

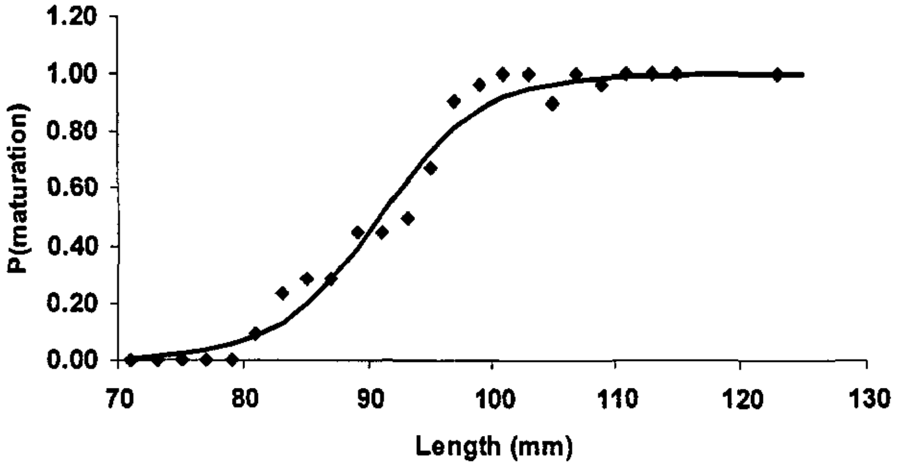


Figure 15: Observed (dots) and predicted (line) proportions of maturity-at-length.

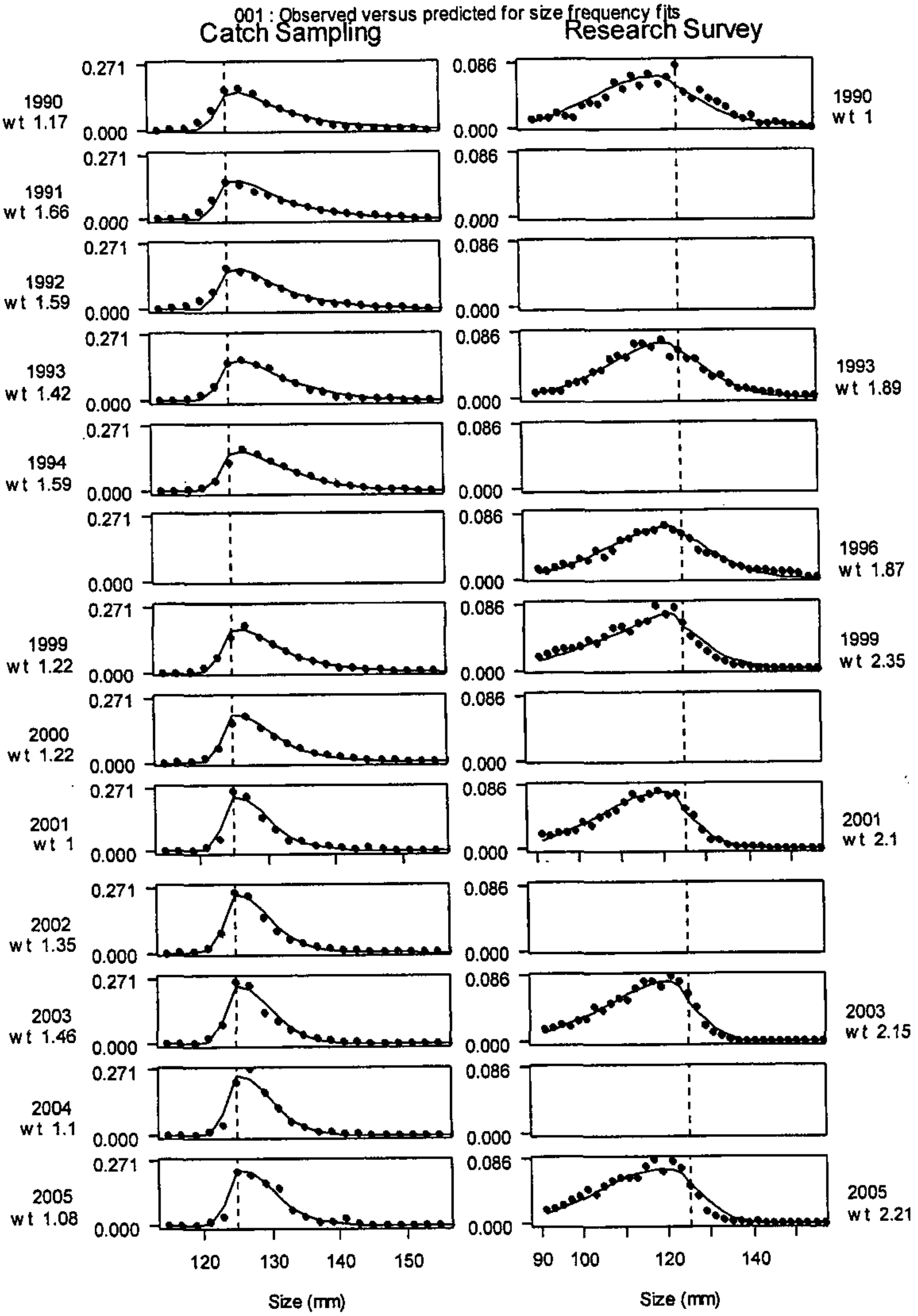


Figure 16: Observed (dots) and predicted (lines) proportions-at-length from commercial catch sampling (left) (CSLF) and research diver surveys (right) (RDLF) for the base case MPD fit for PAU 7. The number under each year is the relative weight given to the dataset, based on the number of paua measured.

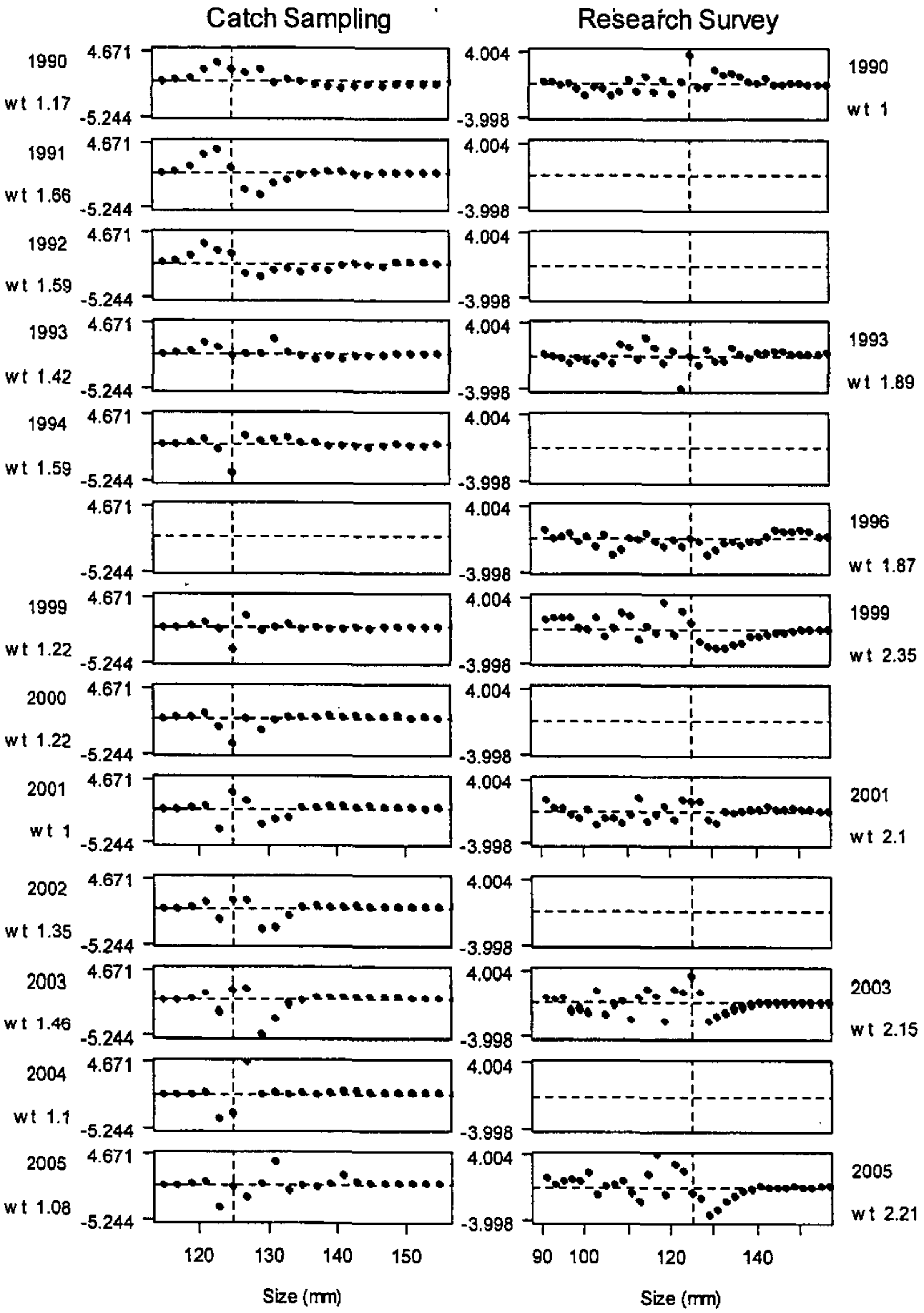


Figure 17: Residuals from base case MPD fits to CSLF (left) and RDLF (right) data seen in Figure 16.

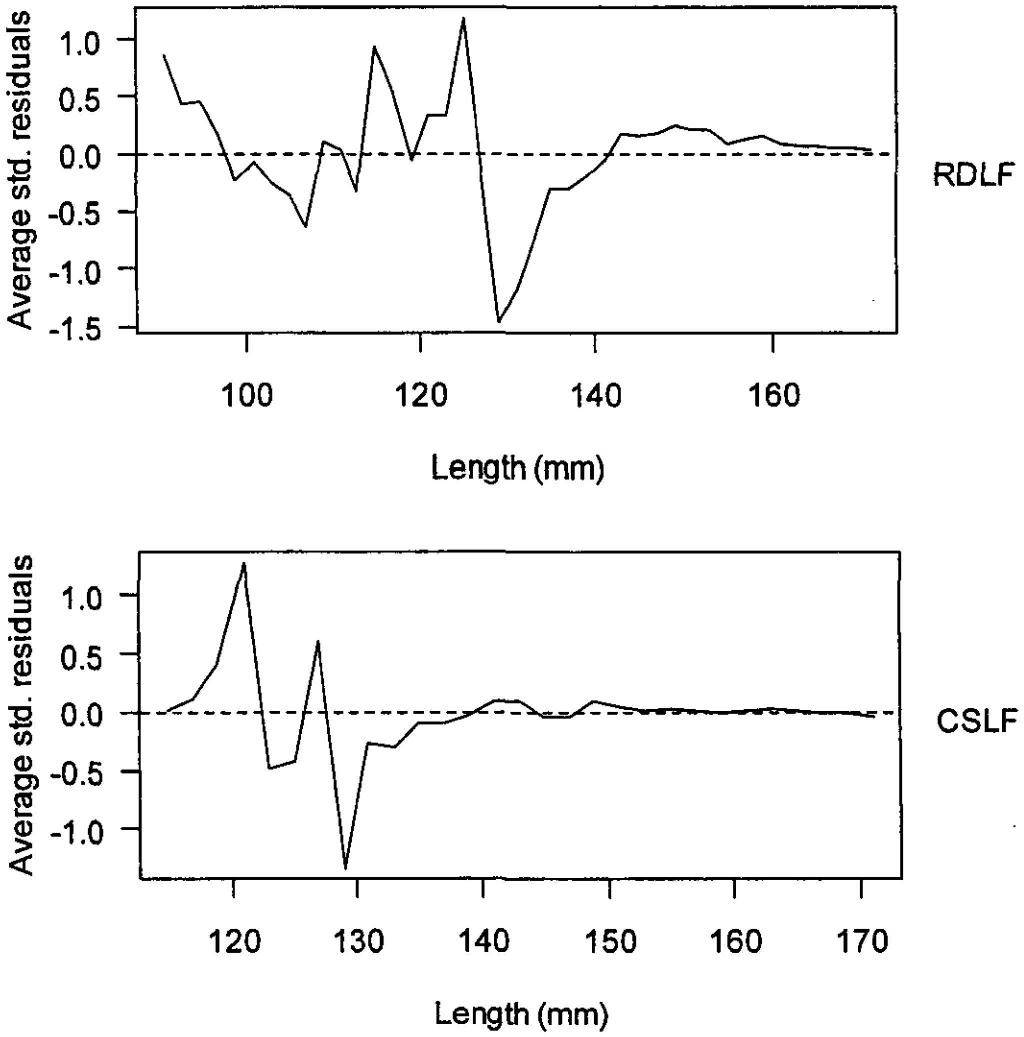


Figure 18: Means of normalised residuals at each length for the fits to the RDLF (upper) and CSLF datasets.

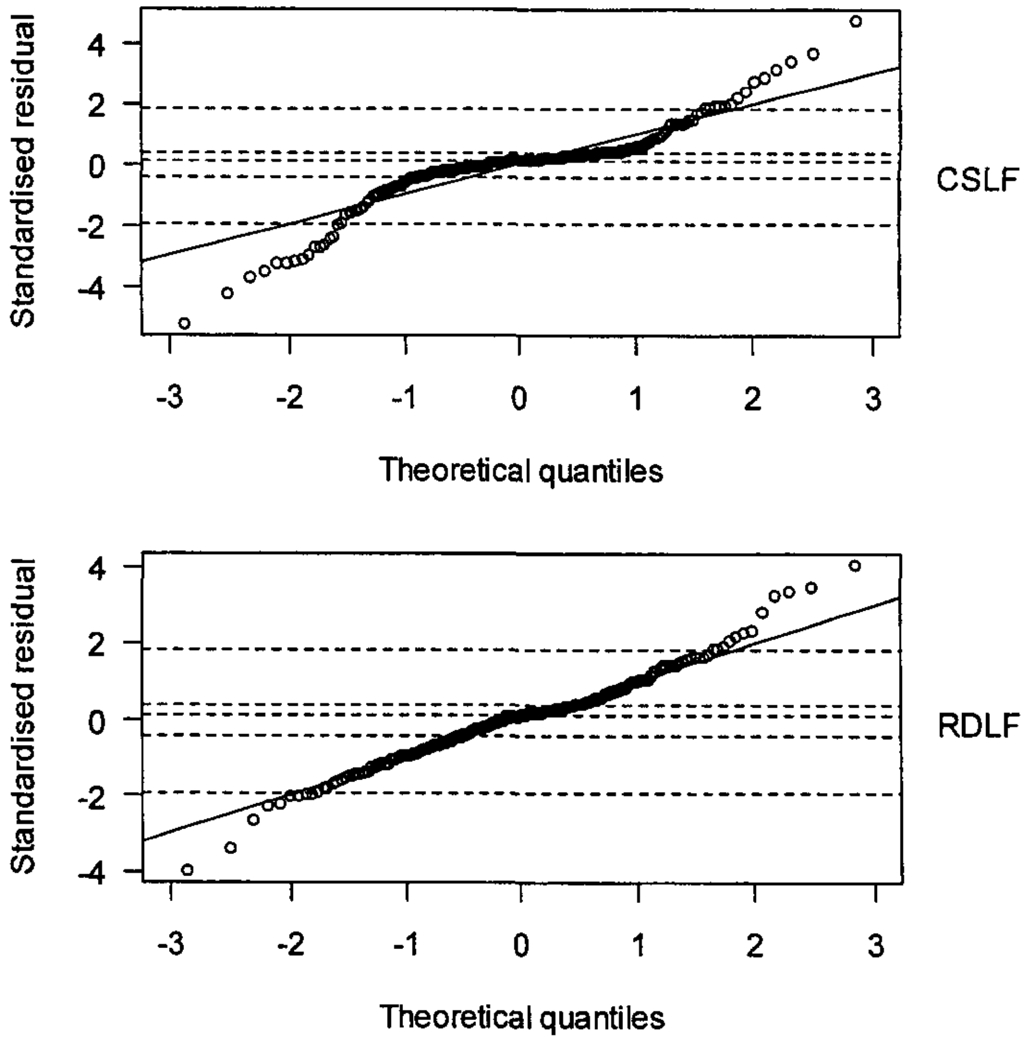


Figure 19: Q-Q plot of residuals for the fits to proportions-at-length from commercial catch sampling (top) and research diver surveys (bottom) from the base case MPD fit for PAU 7.

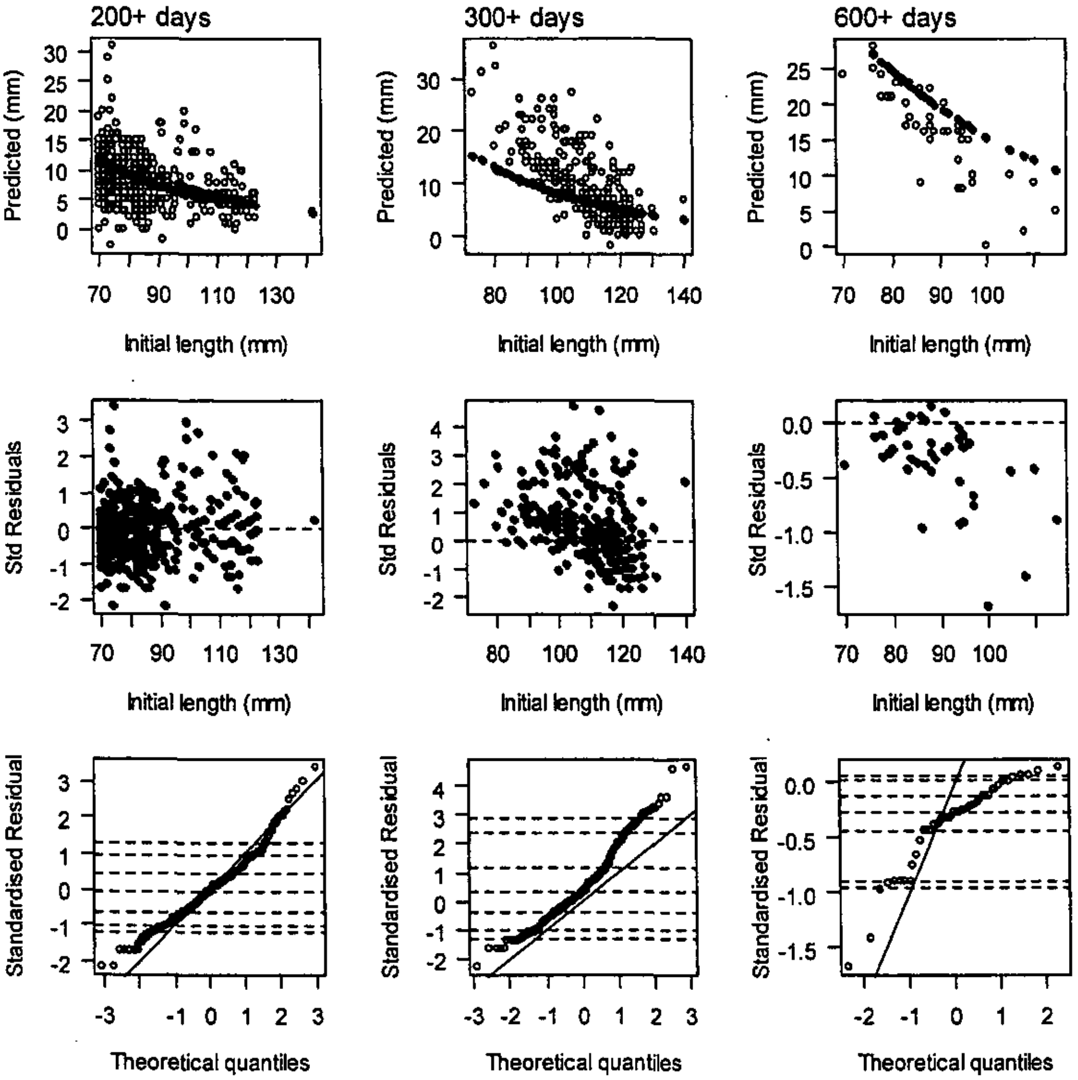


Figure 20: Top: predicted (closed circles) and observed (open circles) increments plotted against initial length of tagged paua from the base case MPD fit for PAU 7; middle: standardised residuals plotted against initial length; bottom: Q-Q plot of standardised residuals. Among the columns, ***the data been divided based on the approximate time-at-liberty, which varied among*** experiments, animals within each experiment having almost the same time-at-liberty.

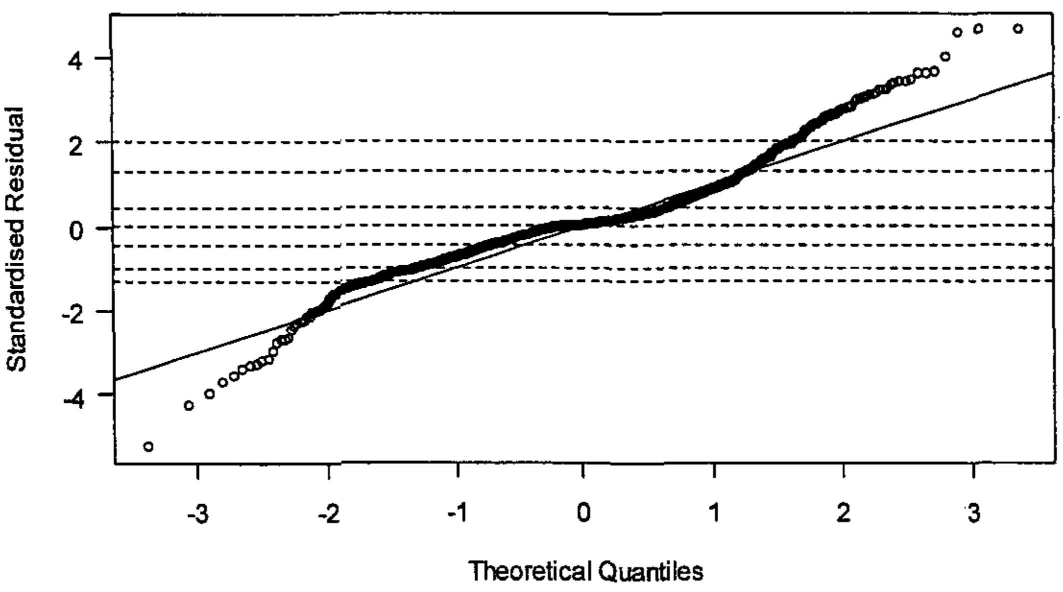


Figure 21: Q-Q plot of the normalised residuals from all datasets used by the model in the base case MPD fit.

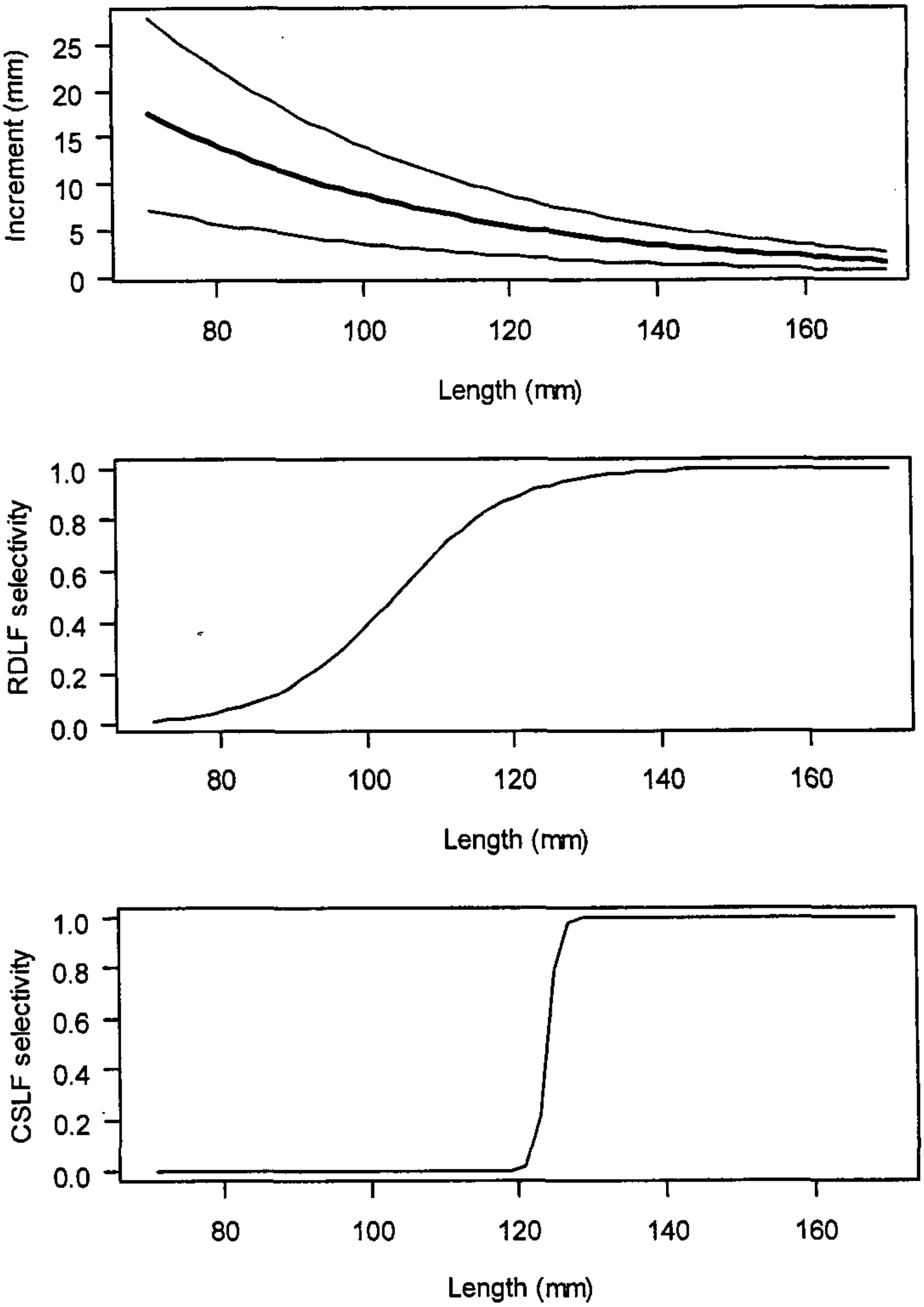


Figure 22: Top: predicted annual growth increment (thick line) *vs.* initial length of paua, shown with one standard deviation around the increment (thin line); middle: estimated research diver survey selectivity; bottom: estimated commercial catch sampling selectivity.

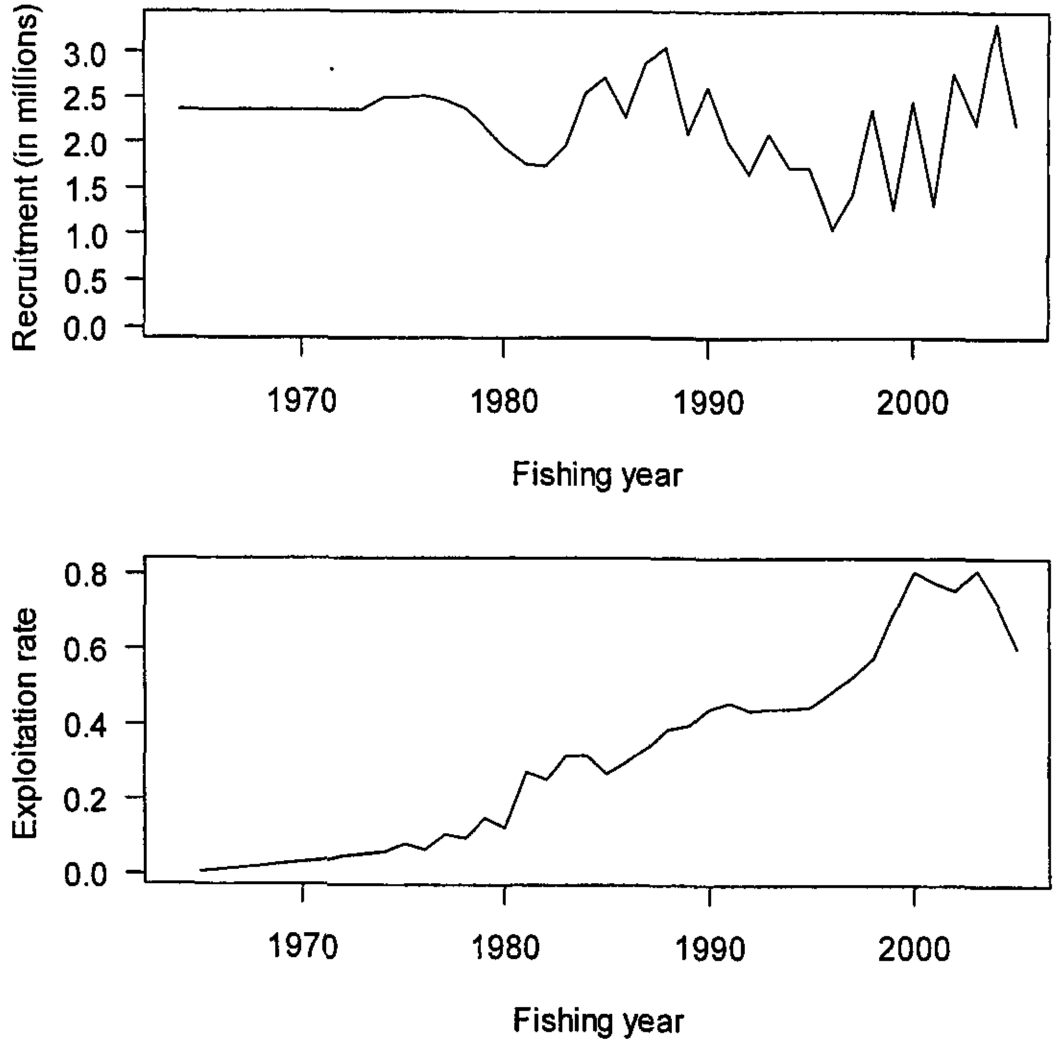


Figure 23: Recruitment to the model (top) and exploitation rate (bottom) from the base case MPD fit in PAU 7.

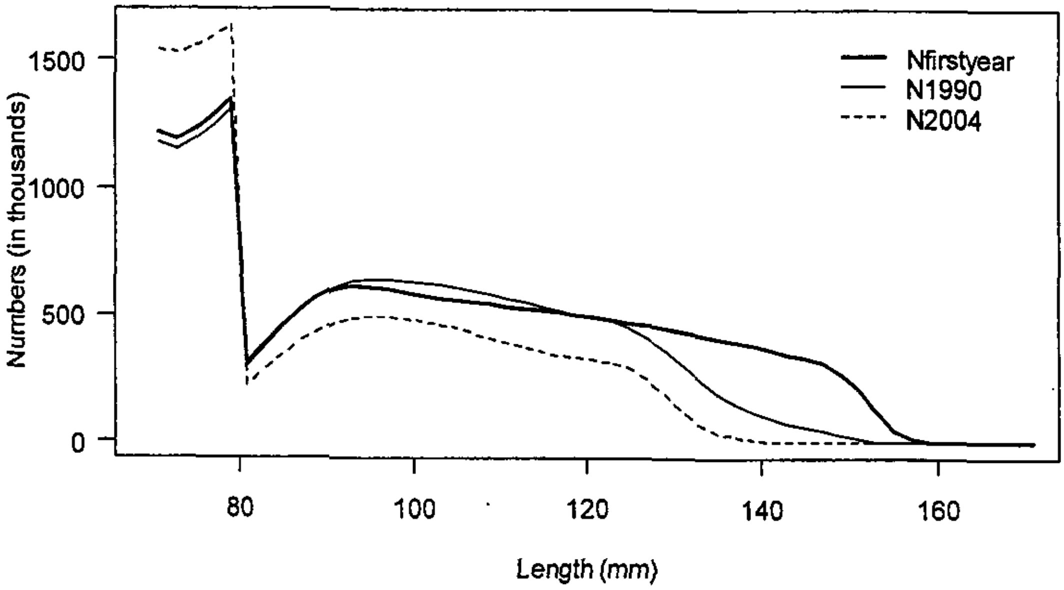


Figure 24: Comparison of size structures in the unfished population (heavy line) and the populations in 1990 (thin line) and 2004 (dashed line) from the base case MPD fit in PAU 7.

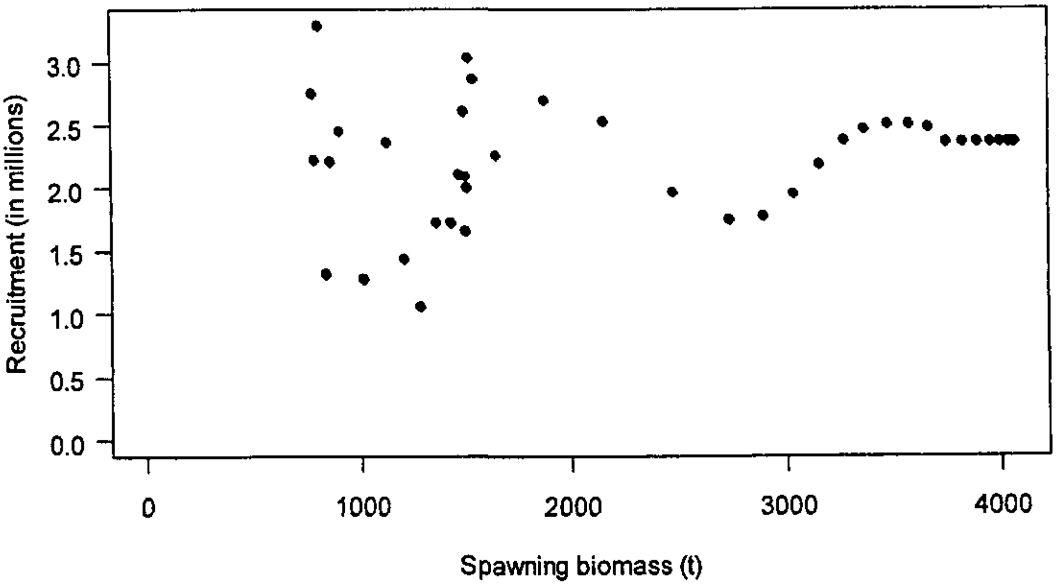


Figure 25: Recruitment plotted against spawning biomass two years earlier from the base case MPD fit in PAU 7.

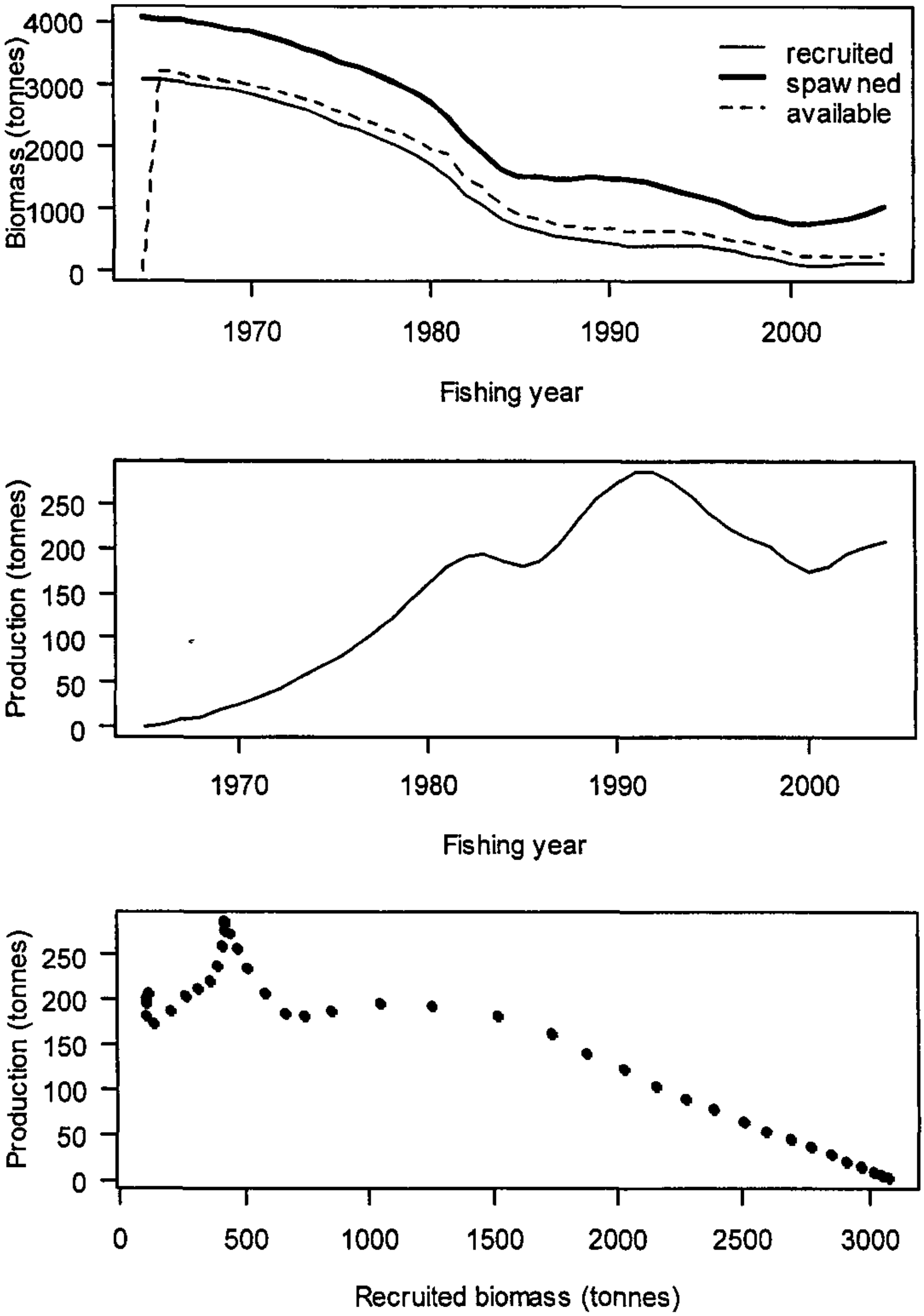


Figure 26: Recruited, spawning and available biomass trajectories (top), the surplus production trajectory (middle) and surplus production plotted against recruited biomass (bottom), all from the base case MPD fit for PAU 7.

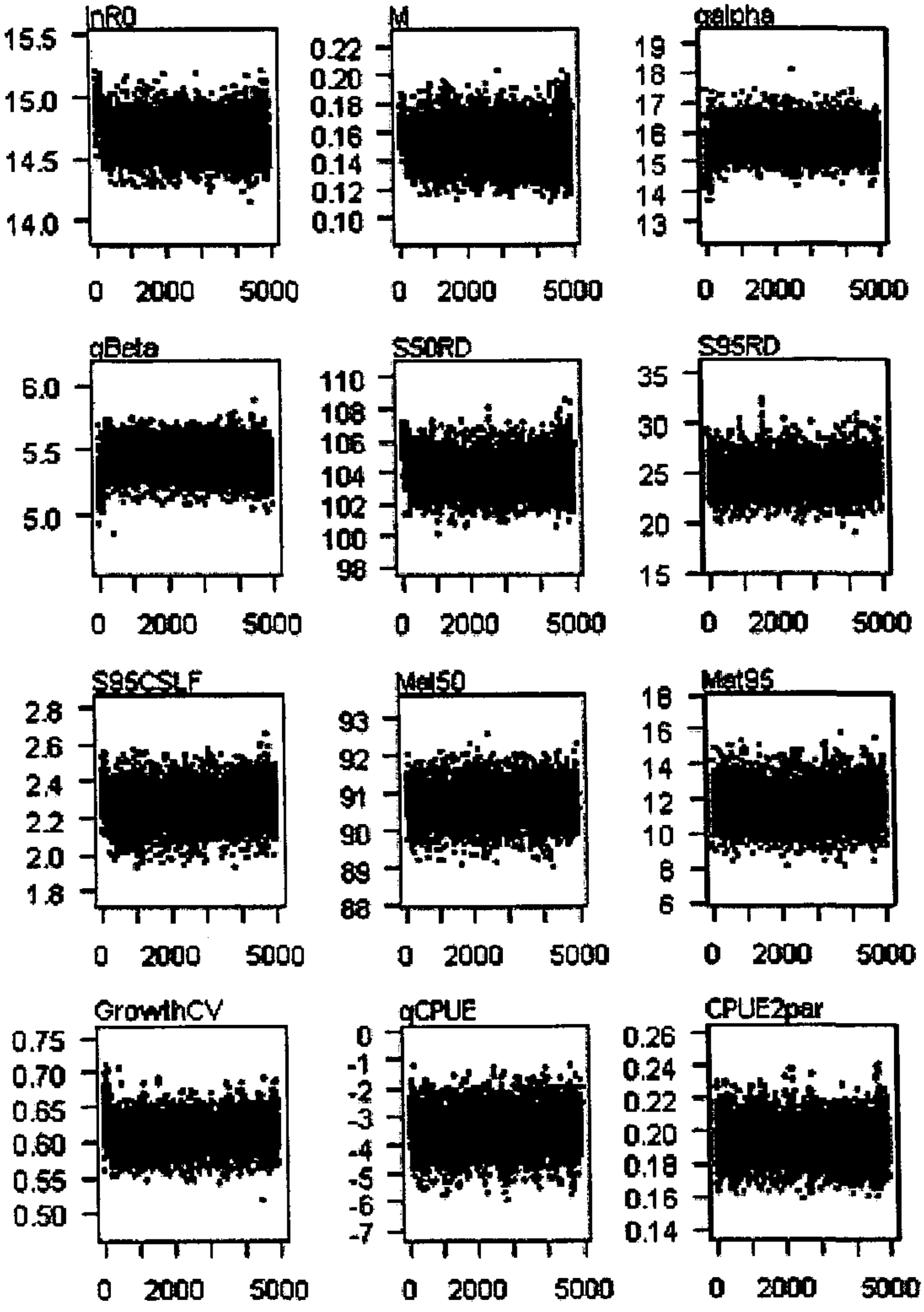


Figure 27: Traces from the PAU 7 base case McMC.

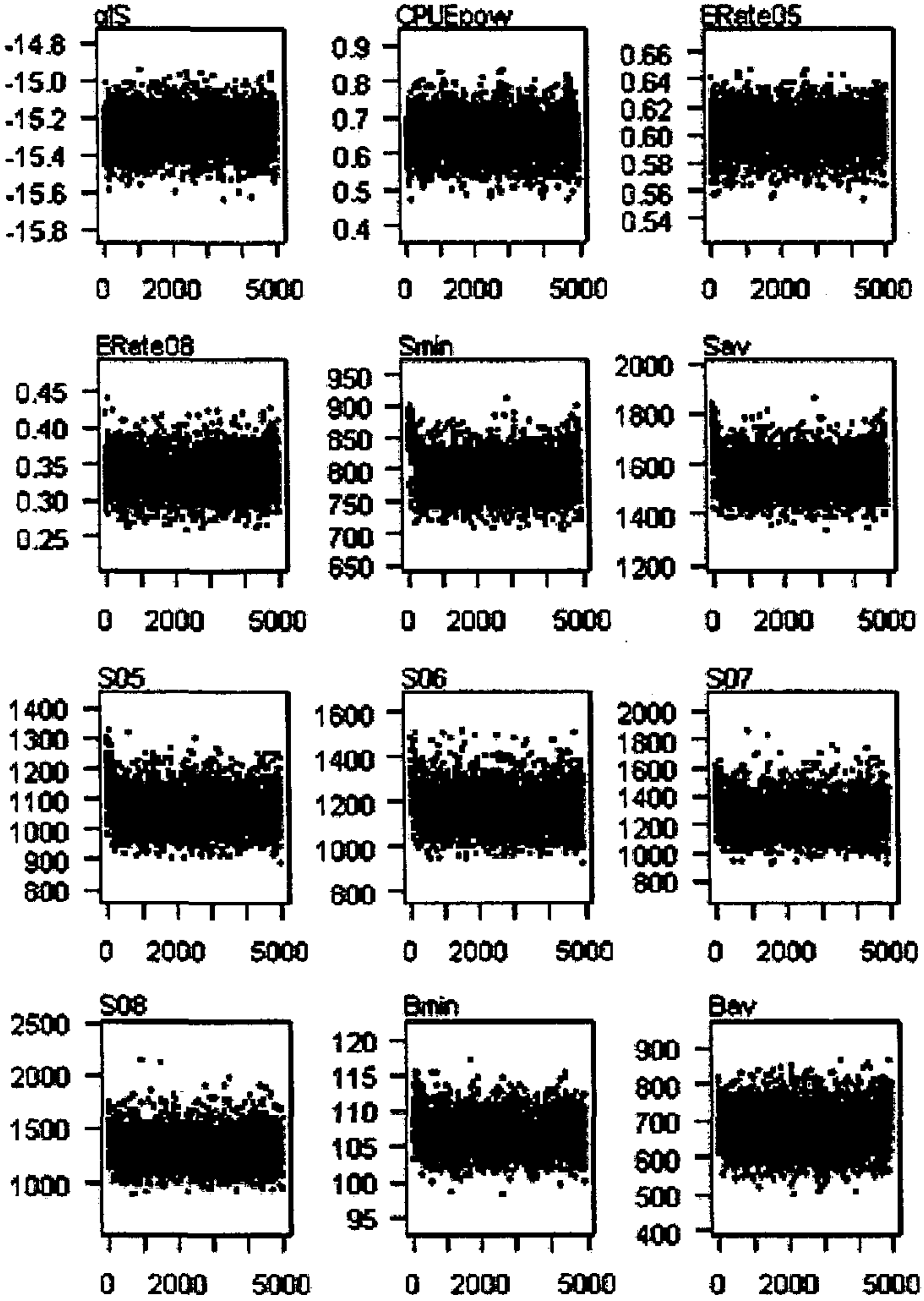


Figure 27 continued.

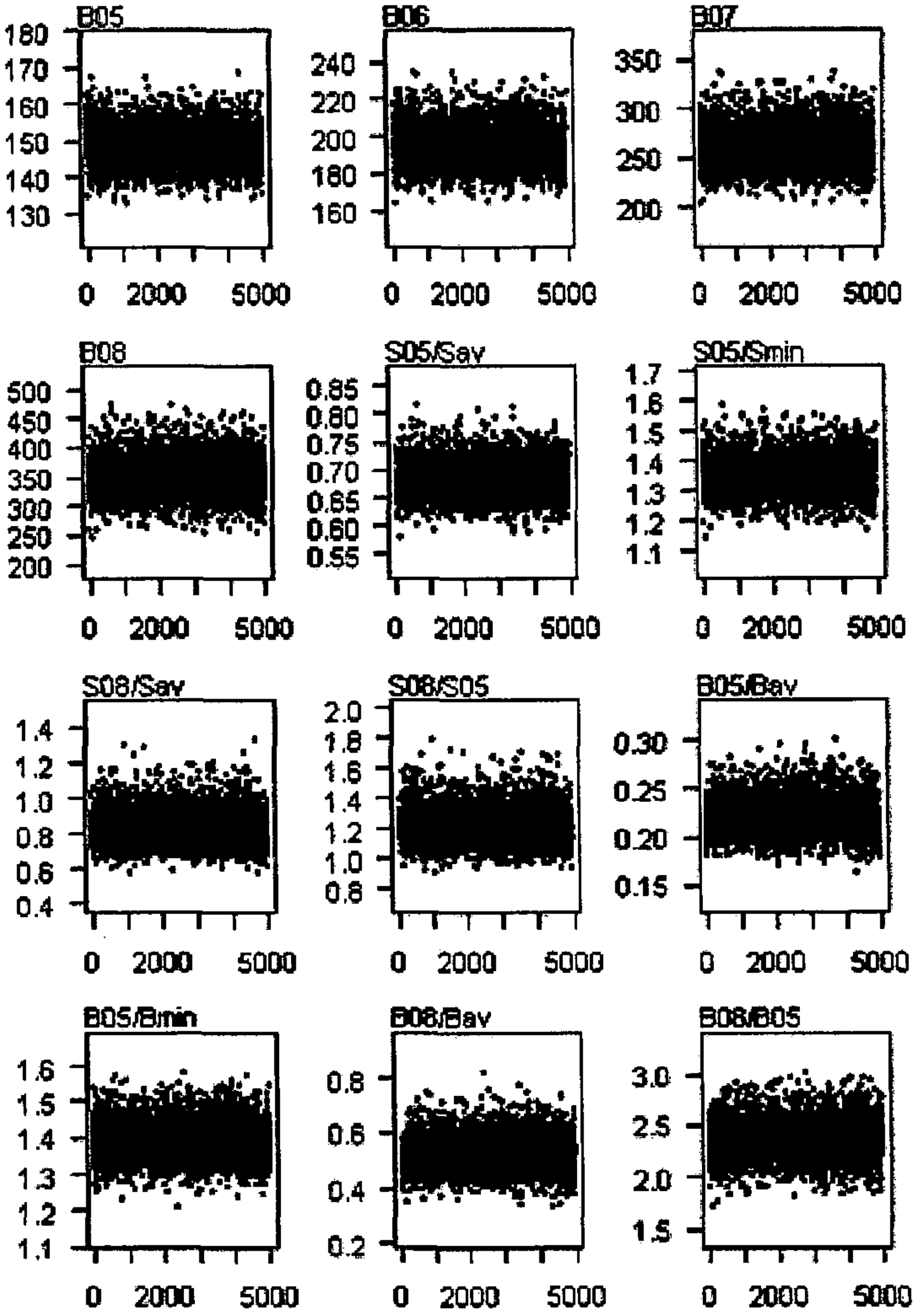
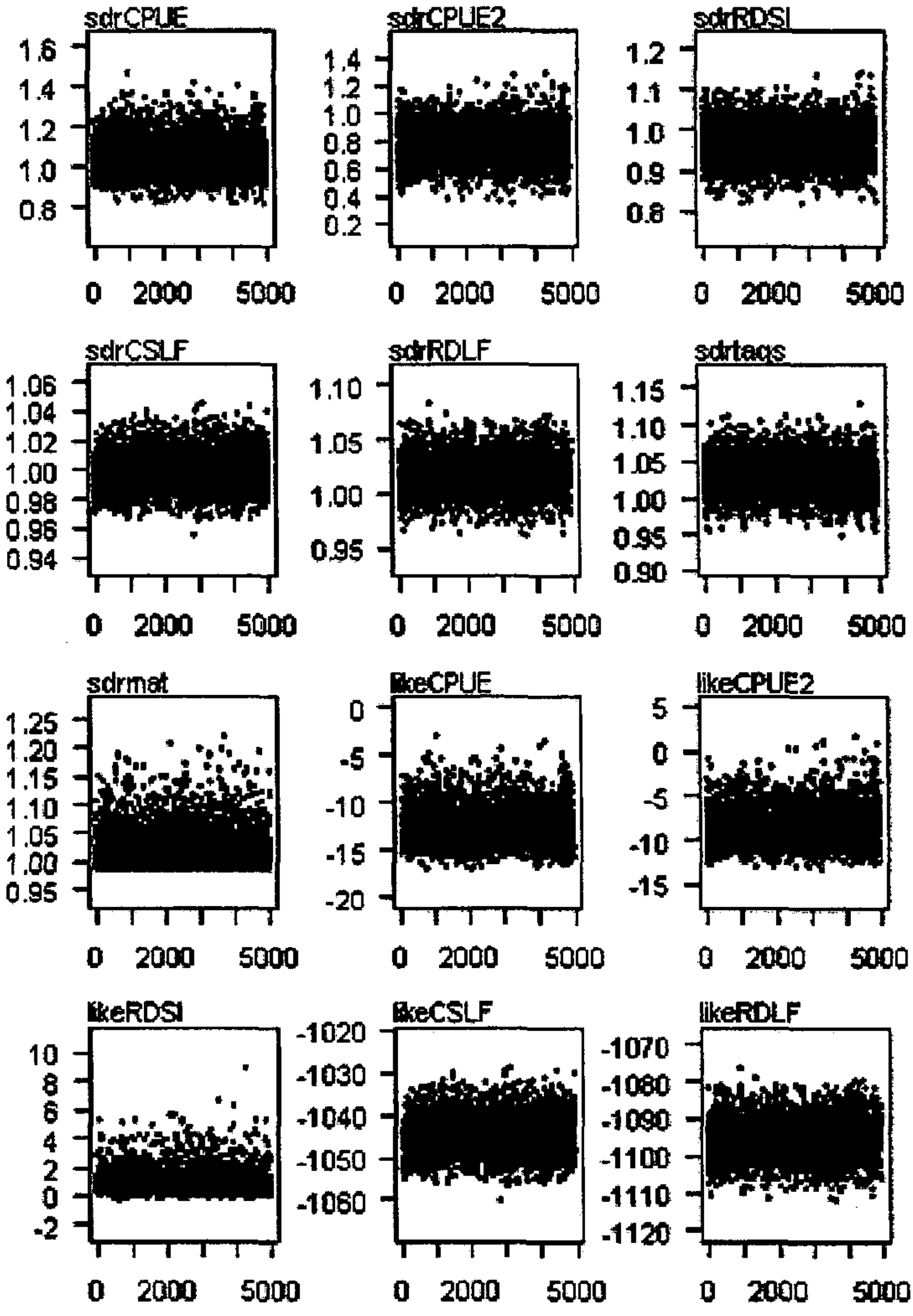


Figure 27 continued.



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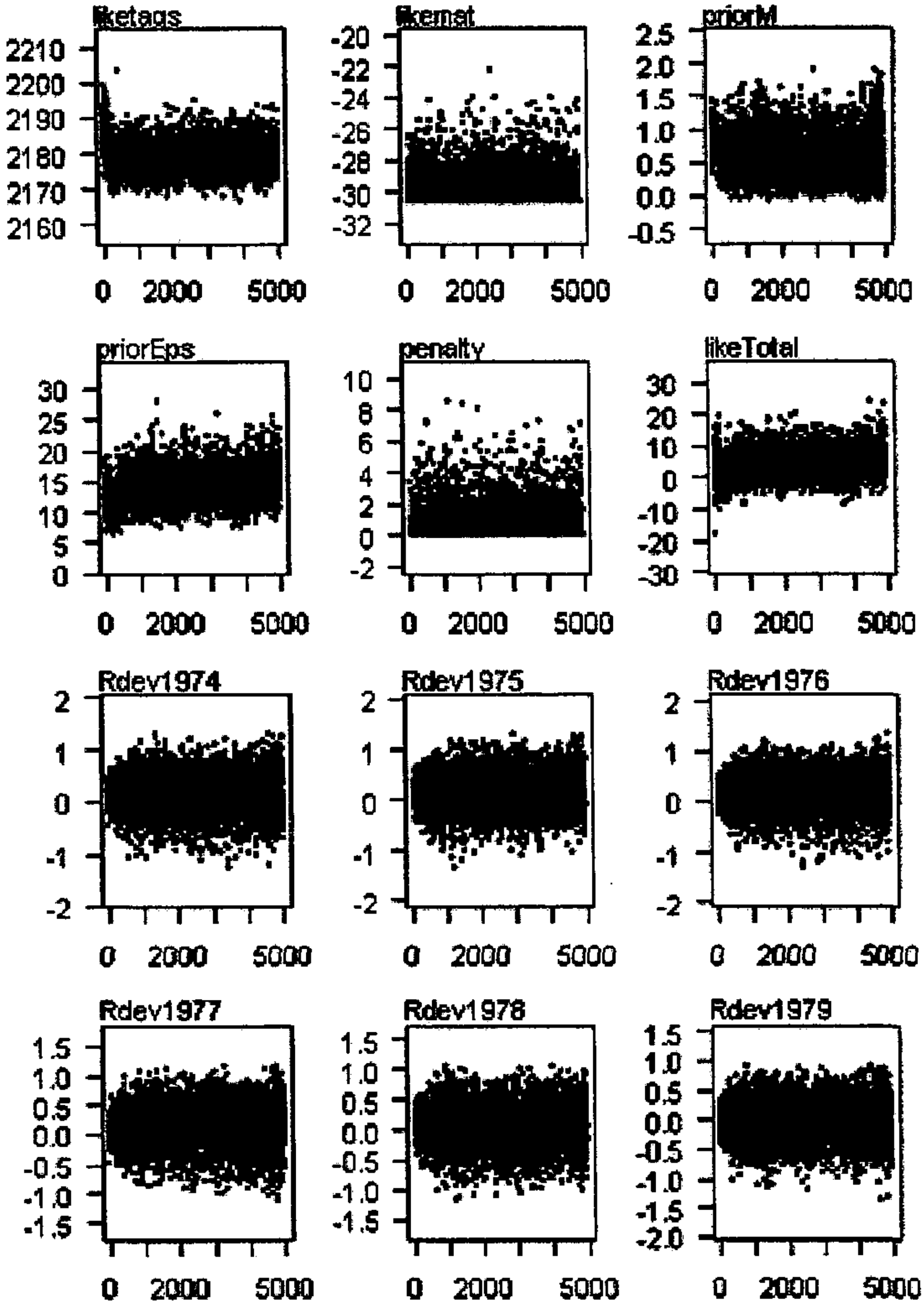

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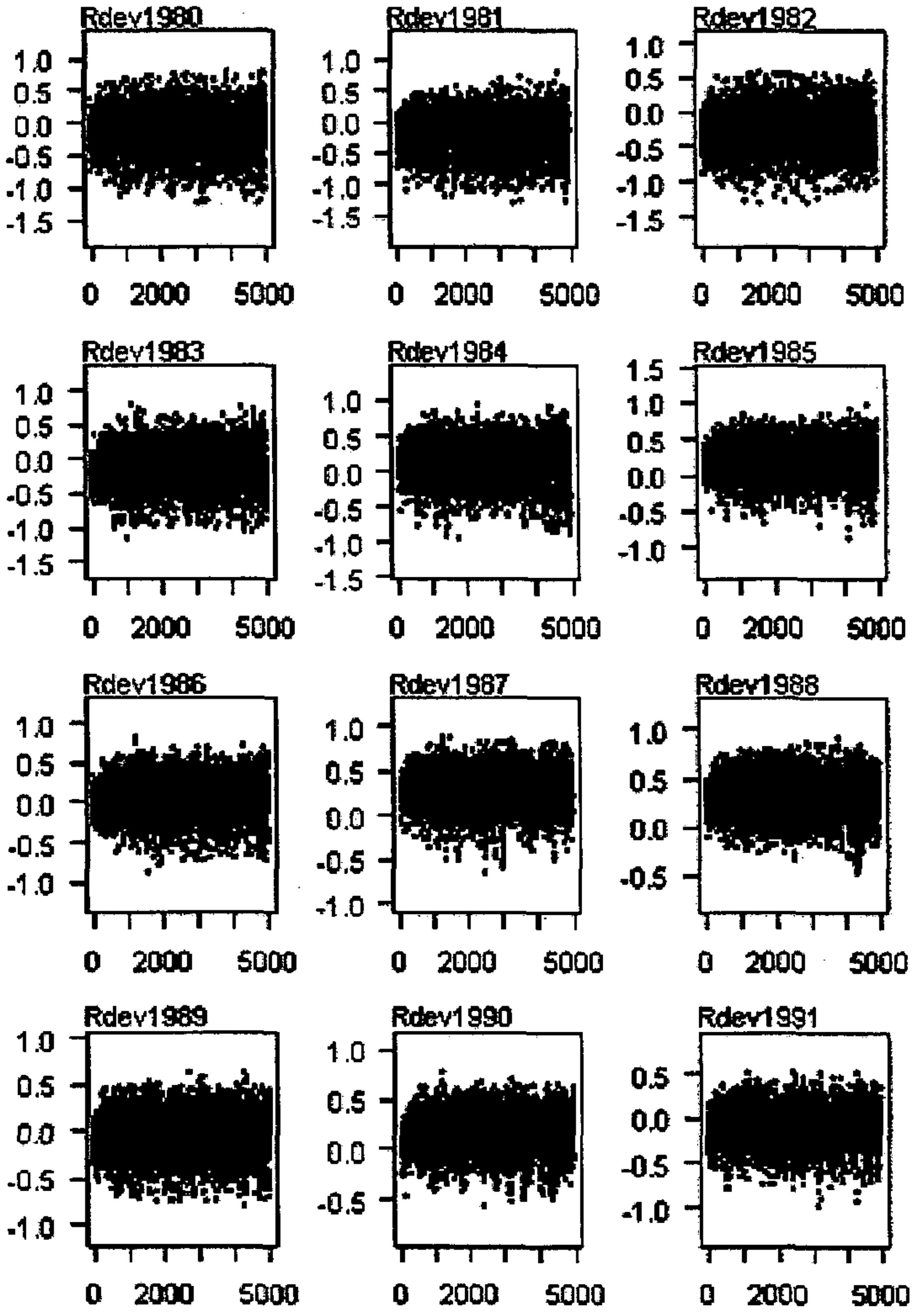
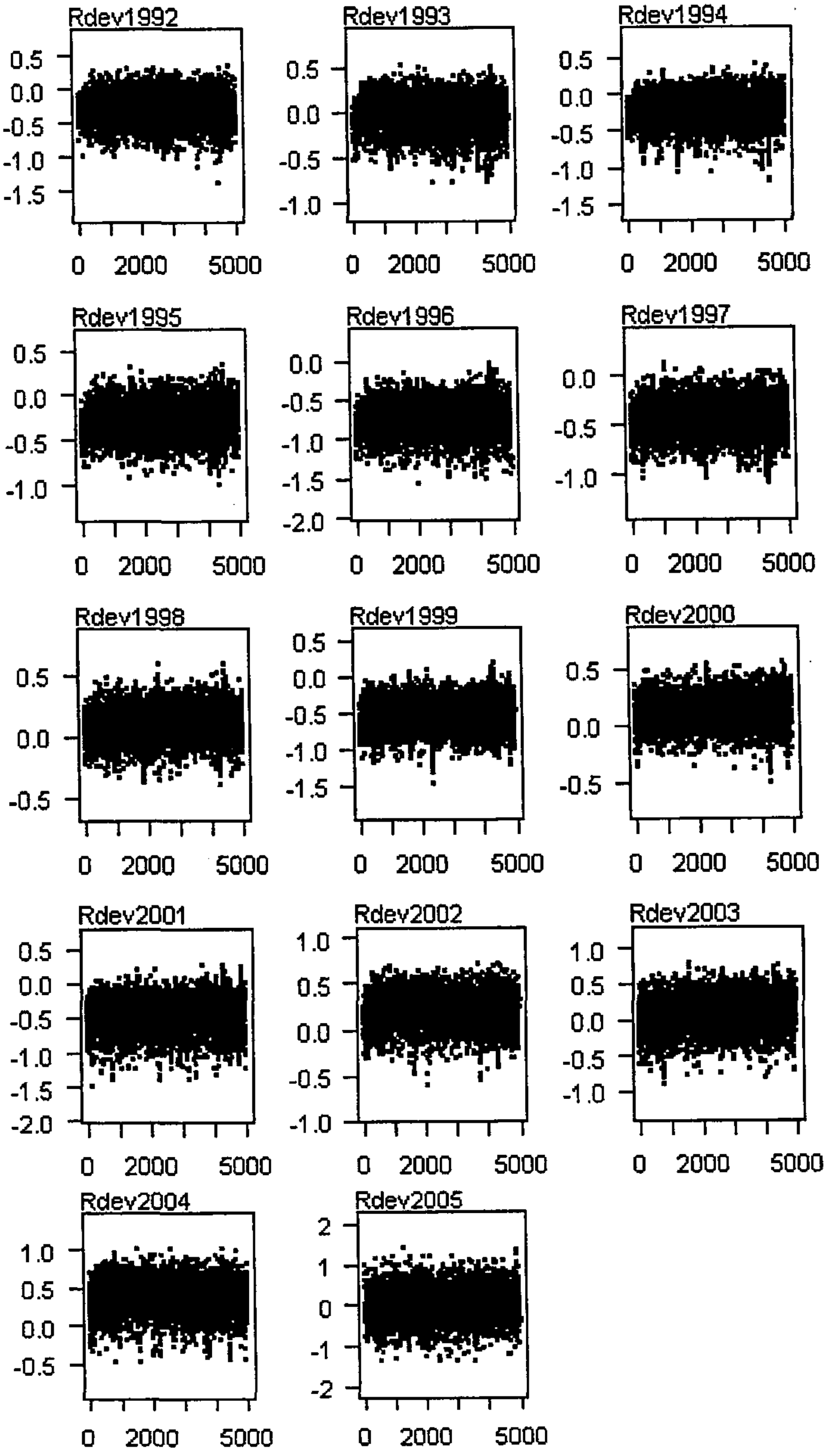


Figure 27 continued.



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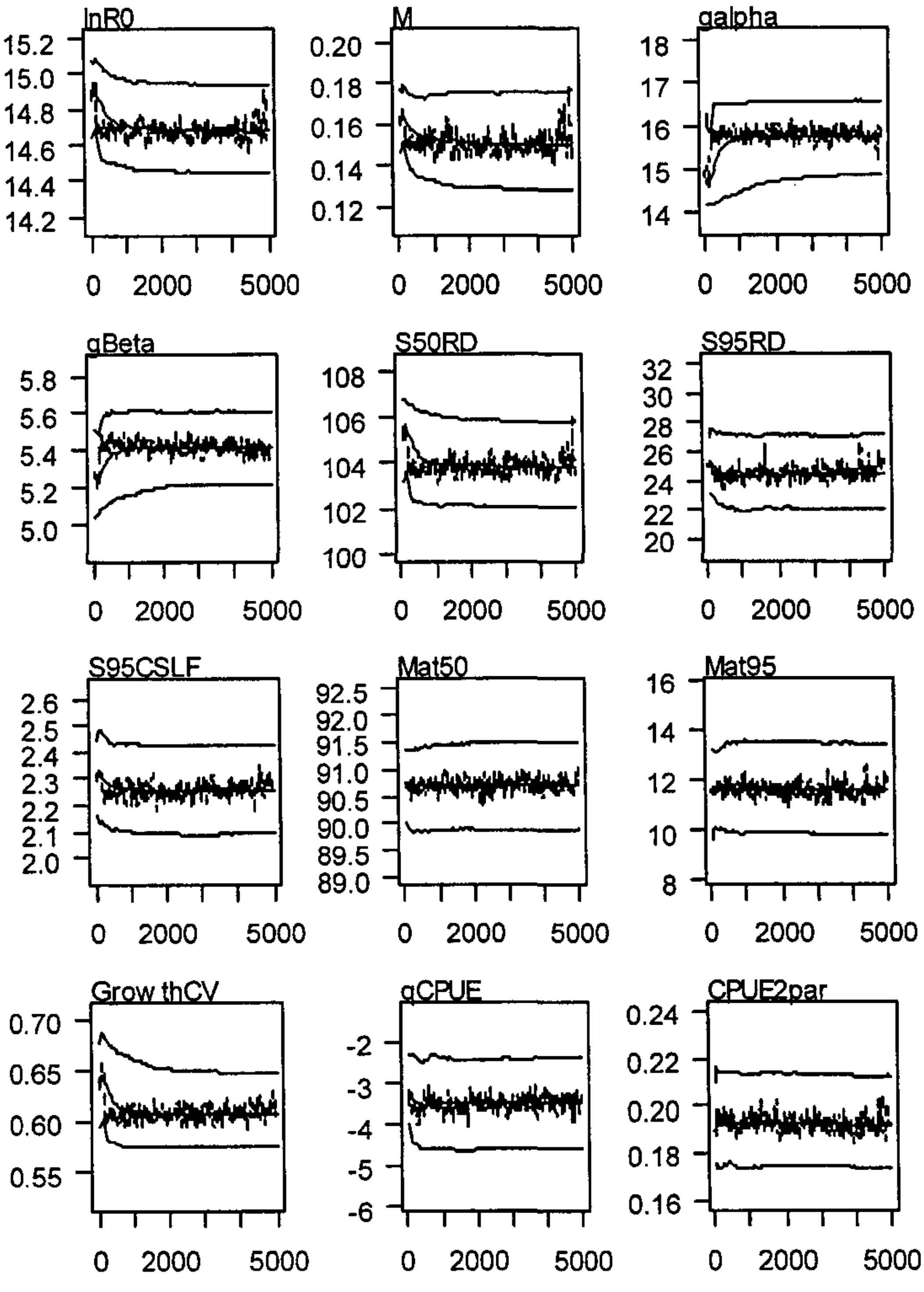


***Figure 28: Diagnostic plots on the traces from the base case PAU 7 McMC simulations.* The central line is the running median; the upper and lower lines are the running 5th and 95th quantiles; the central dots show a moving average over 40 samples.**

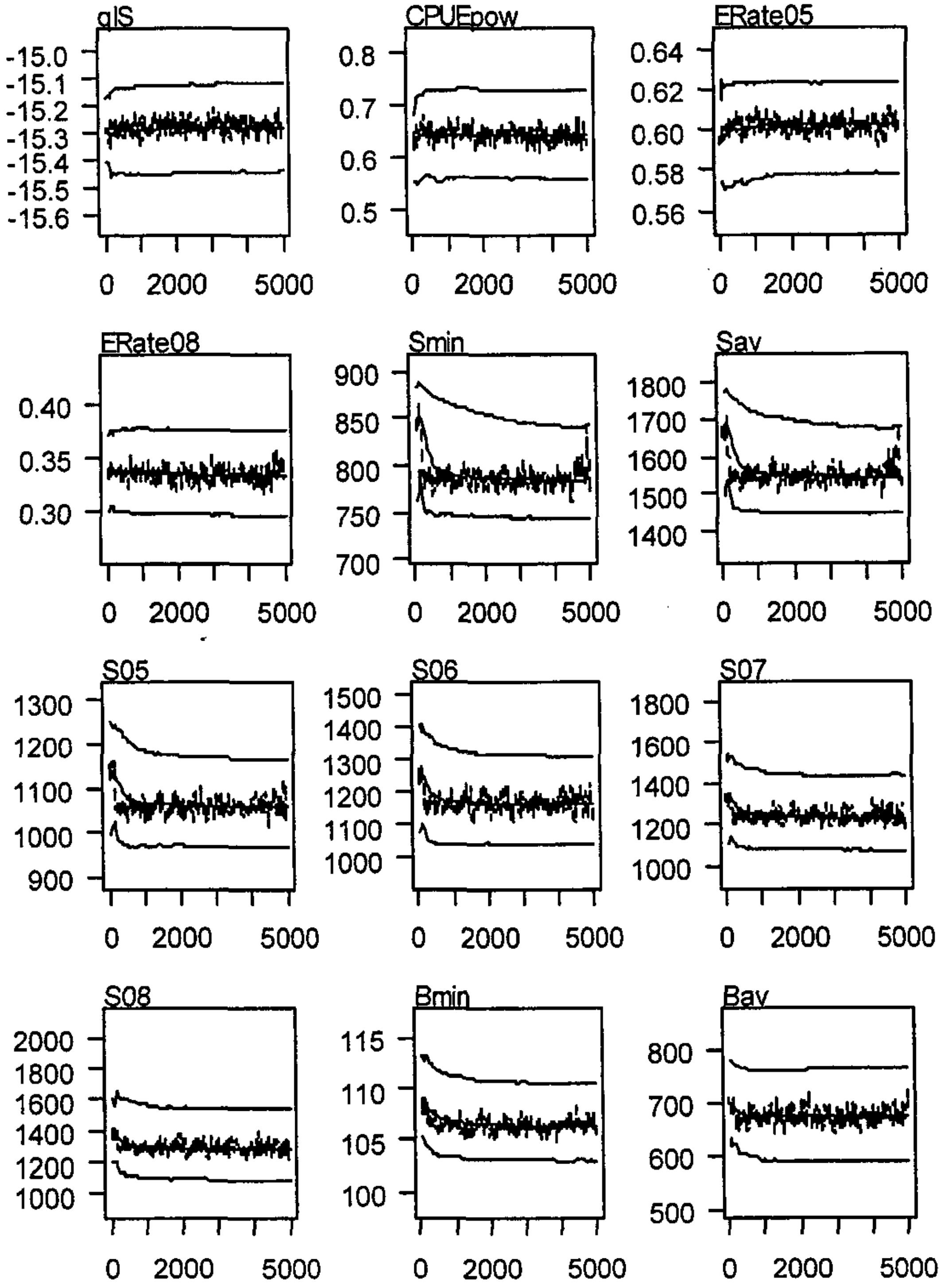


Figure 28 continued.

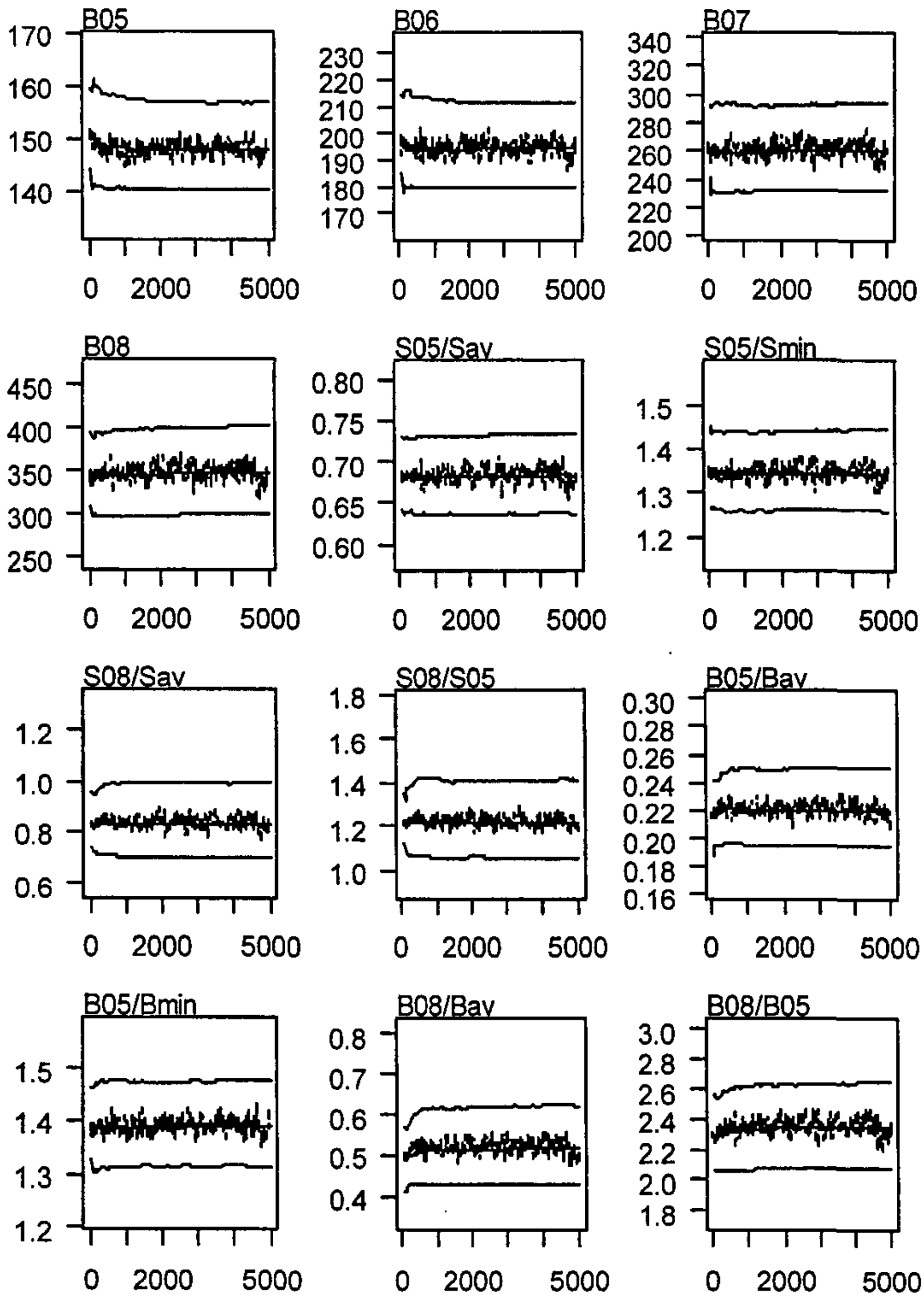


Figure 28 continued.

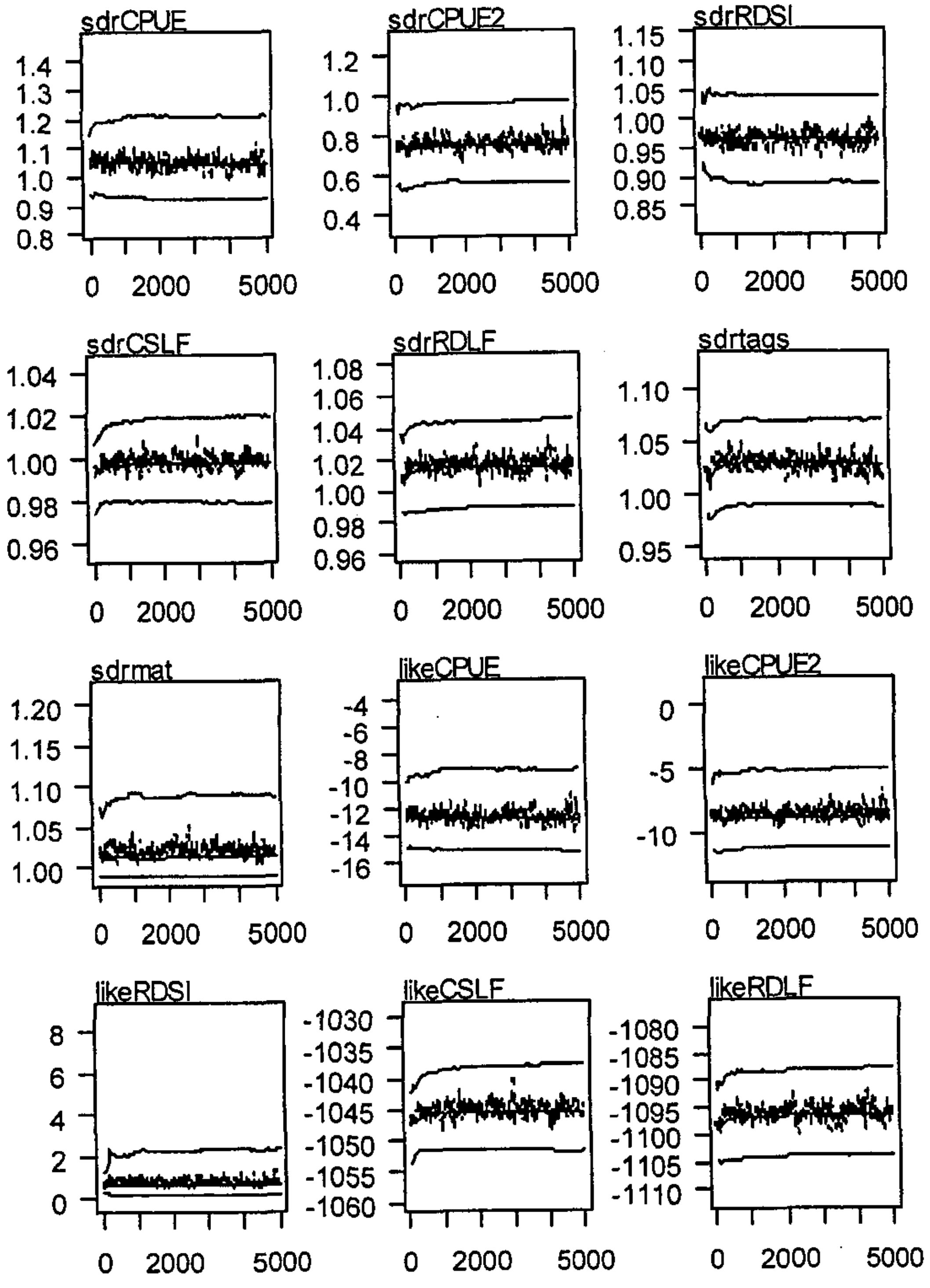
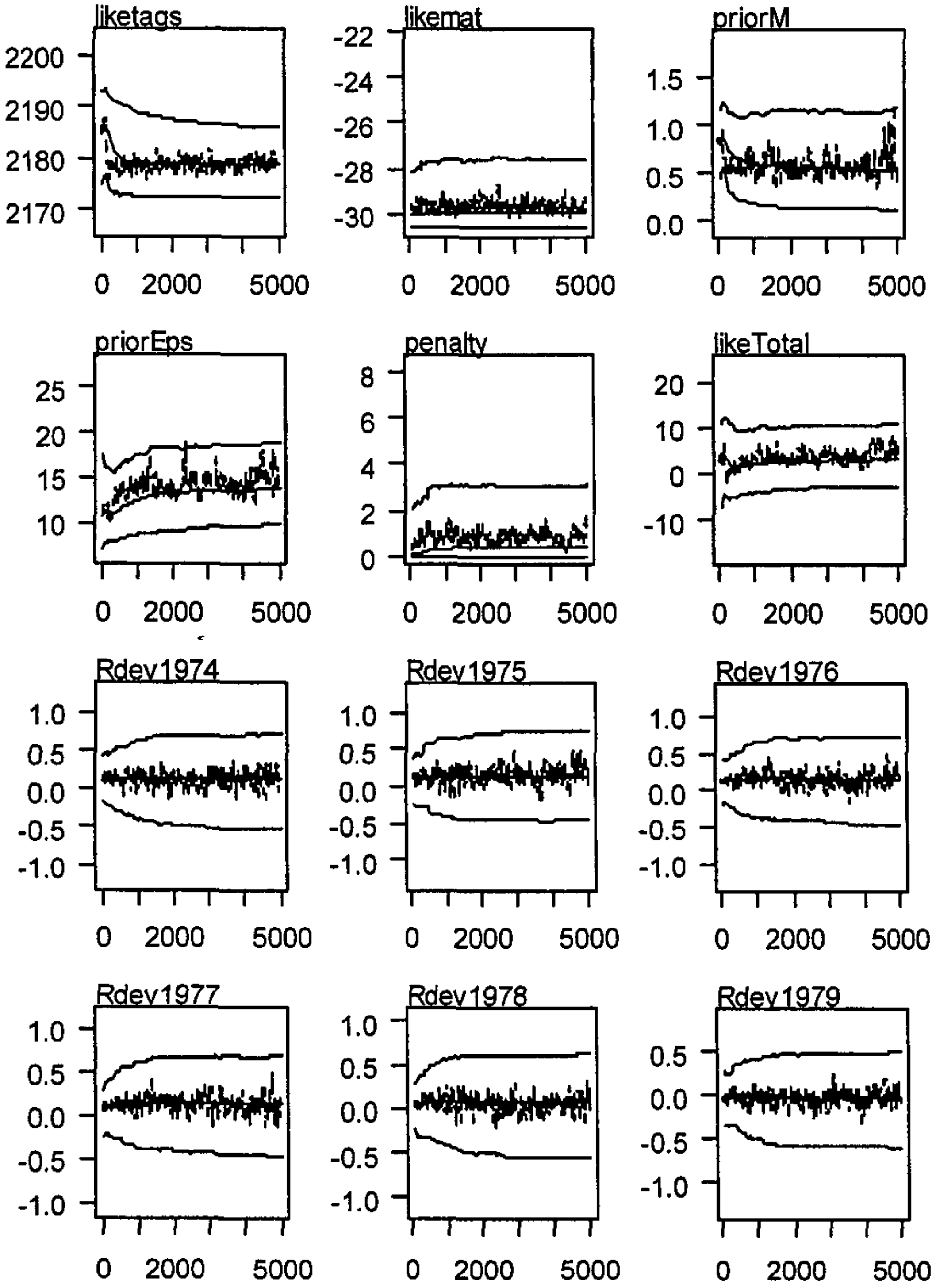


Figure 28 continued.



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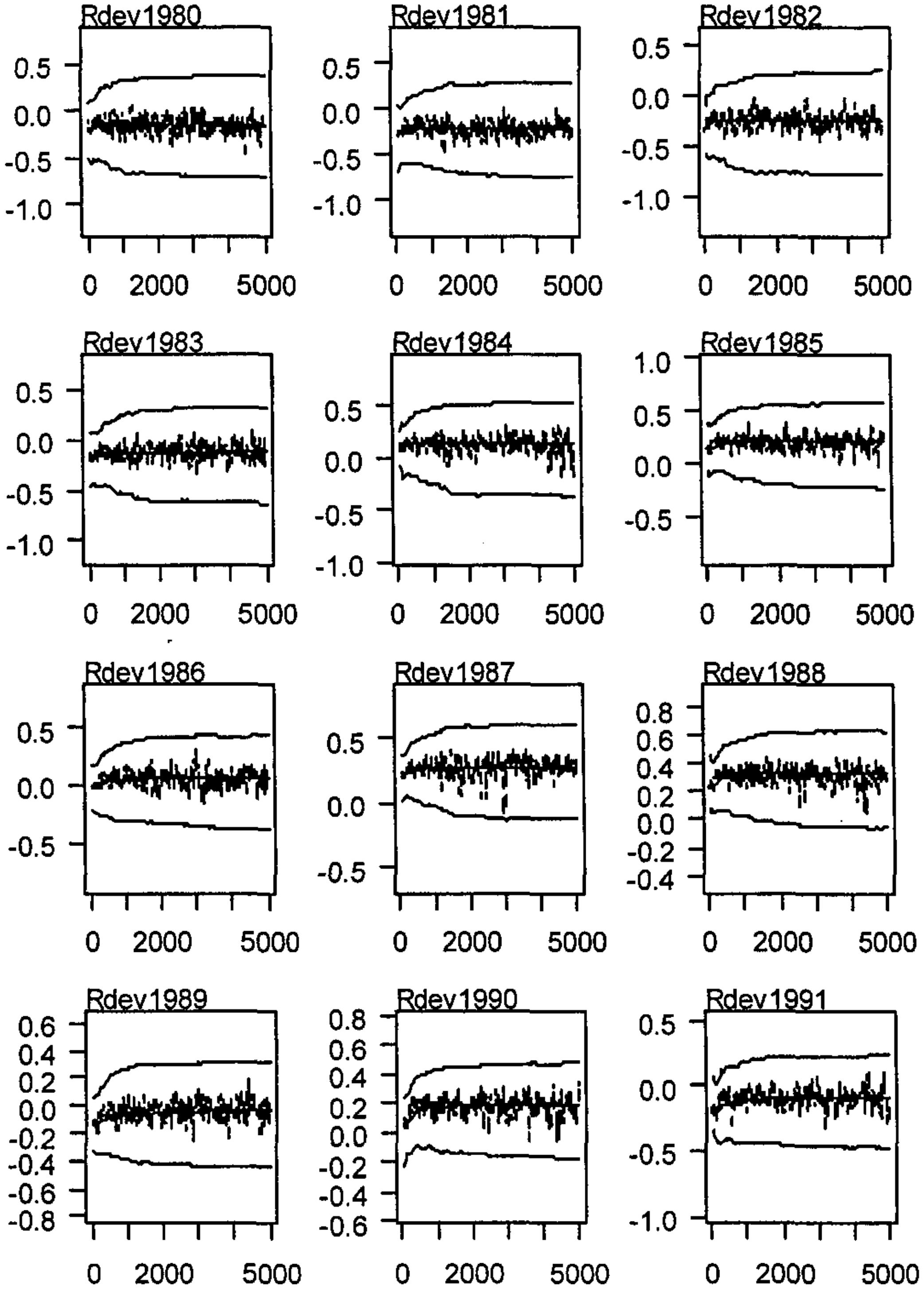

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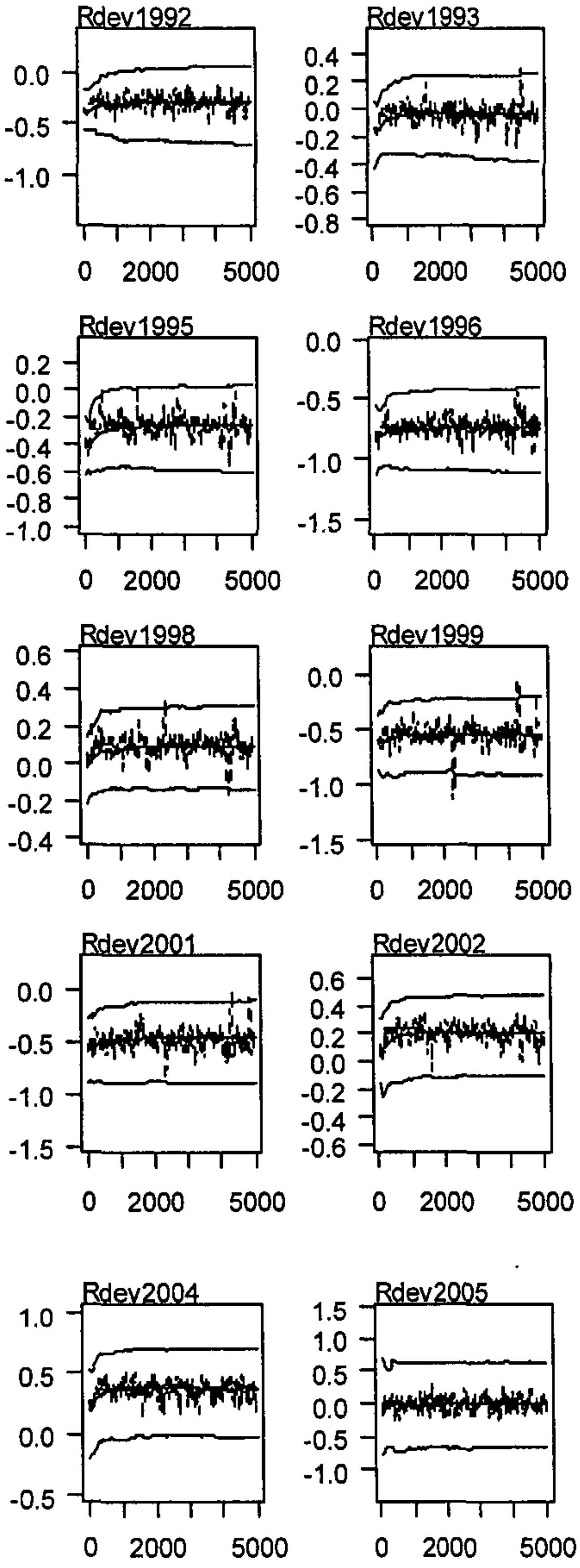

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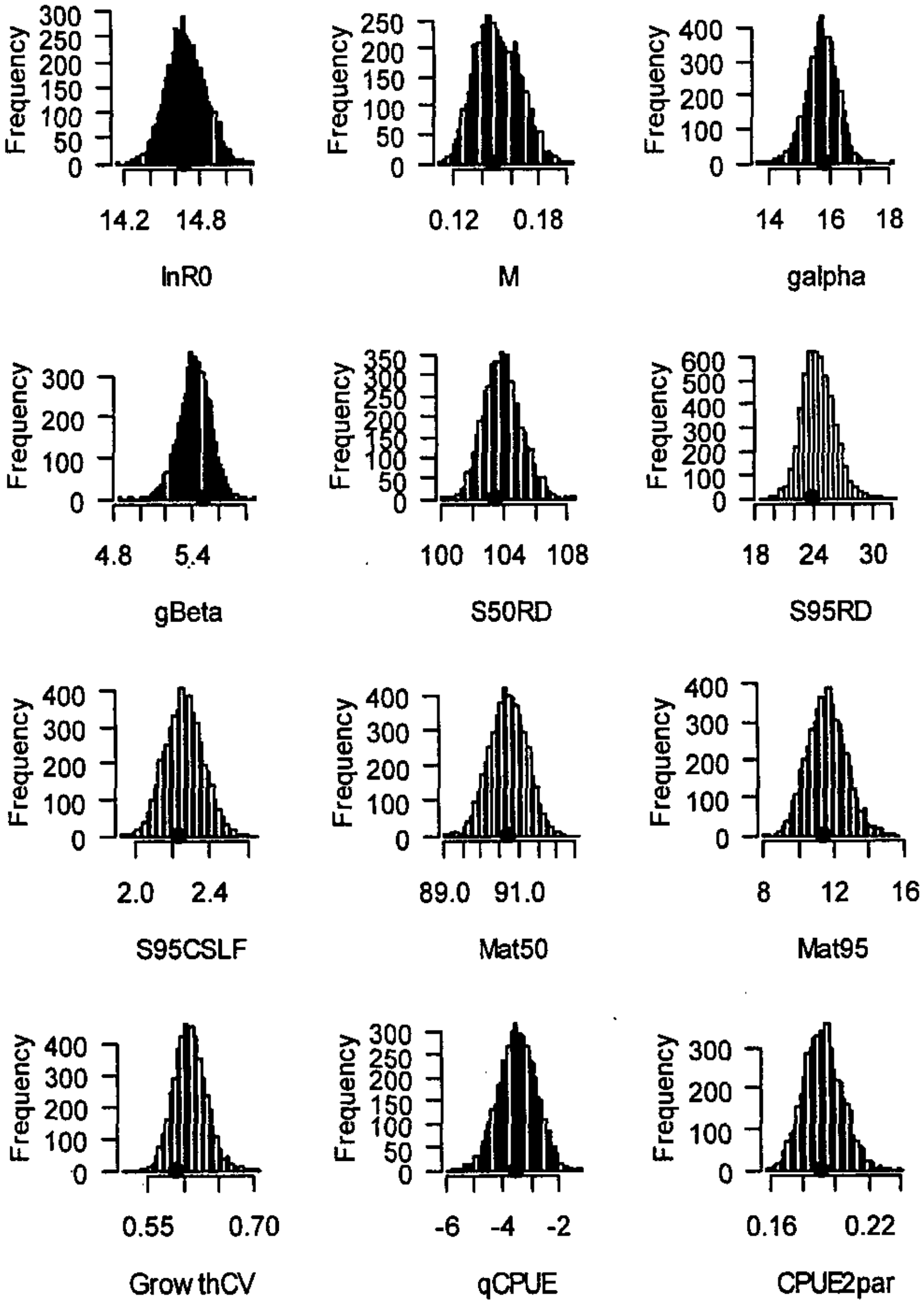
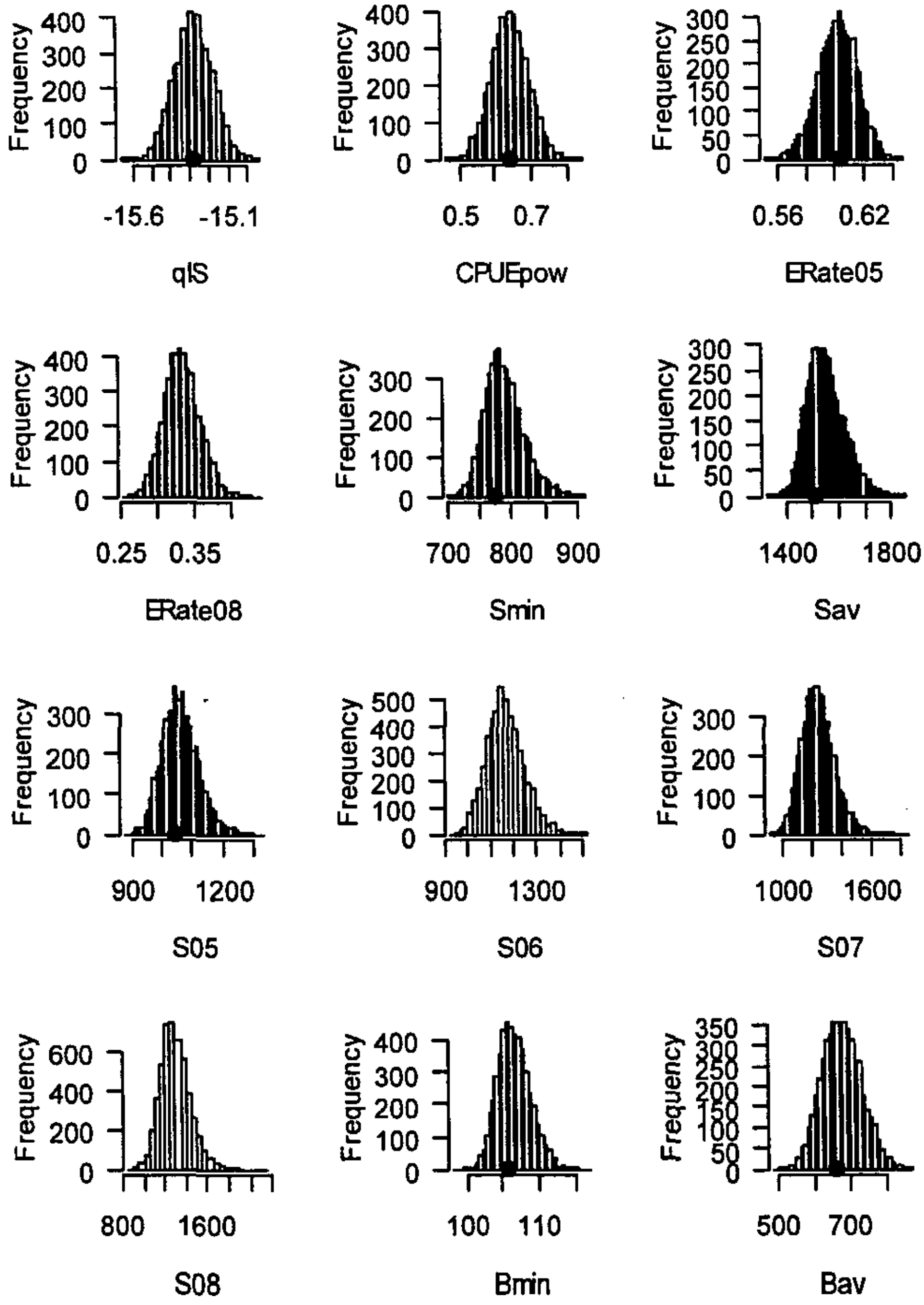


Figure 29: Posterior distributions of parameters and indicators from base case PAU 7 McMC. Dots on the x-axis show the MPD estimate.



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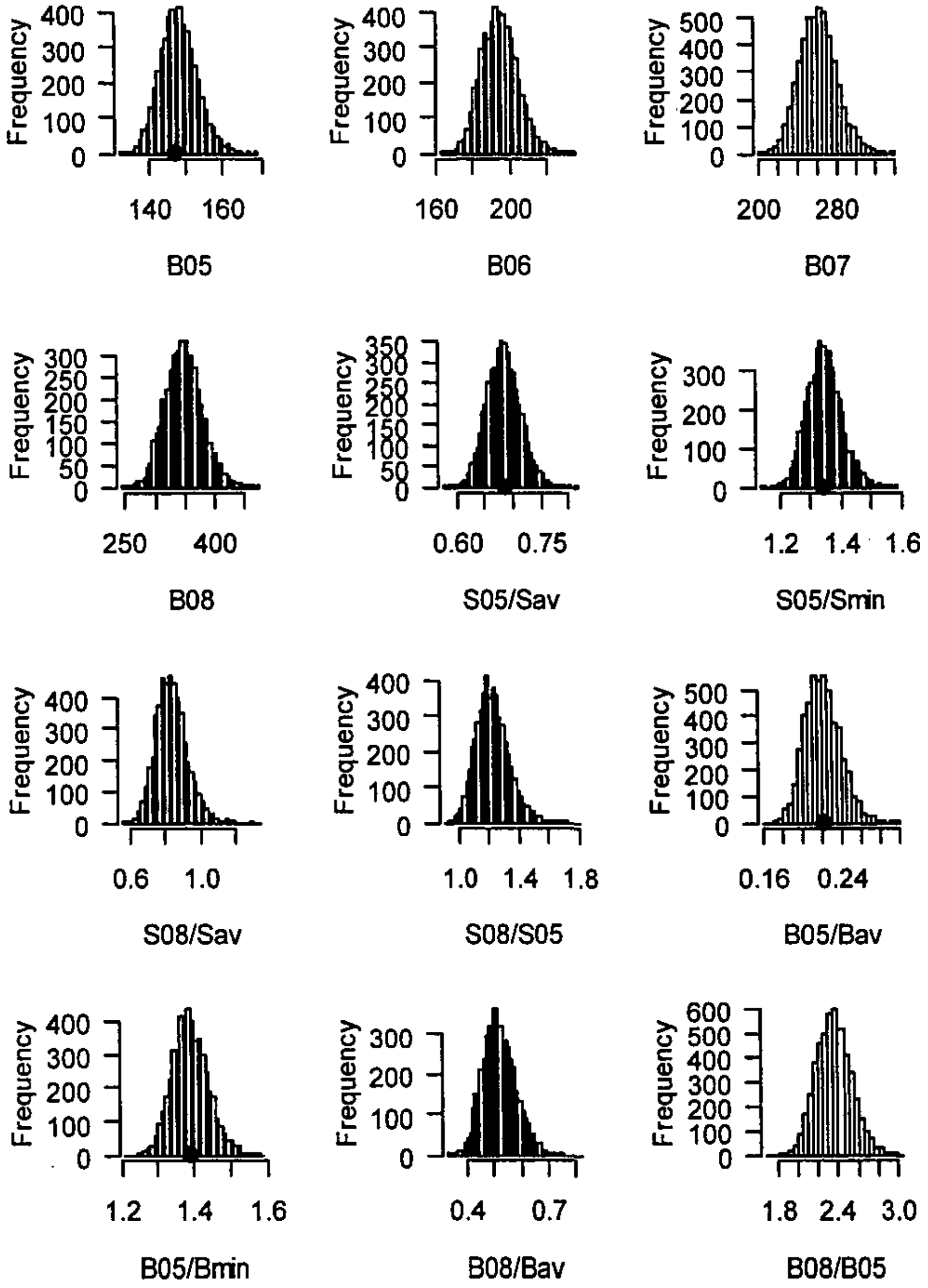

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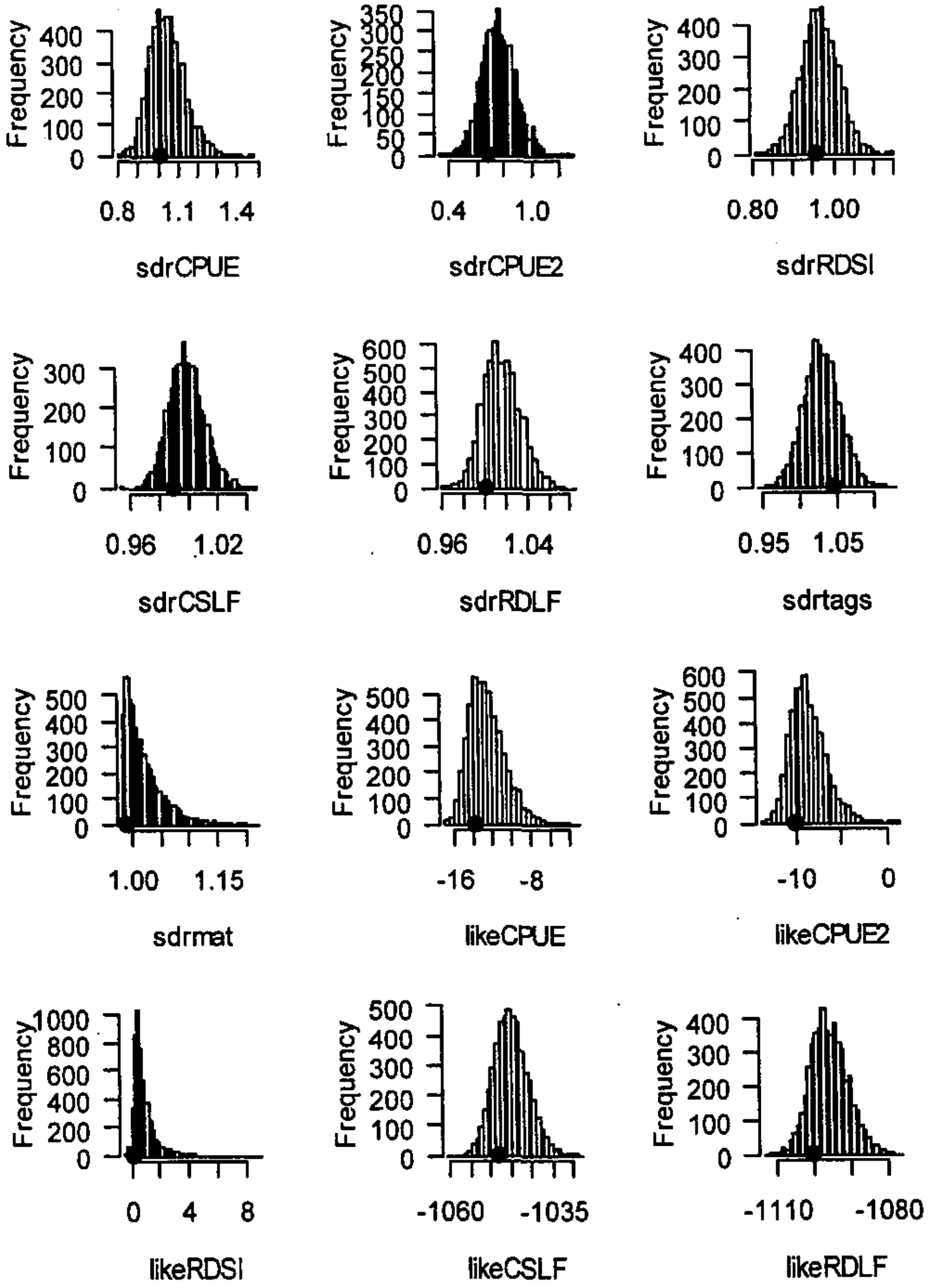

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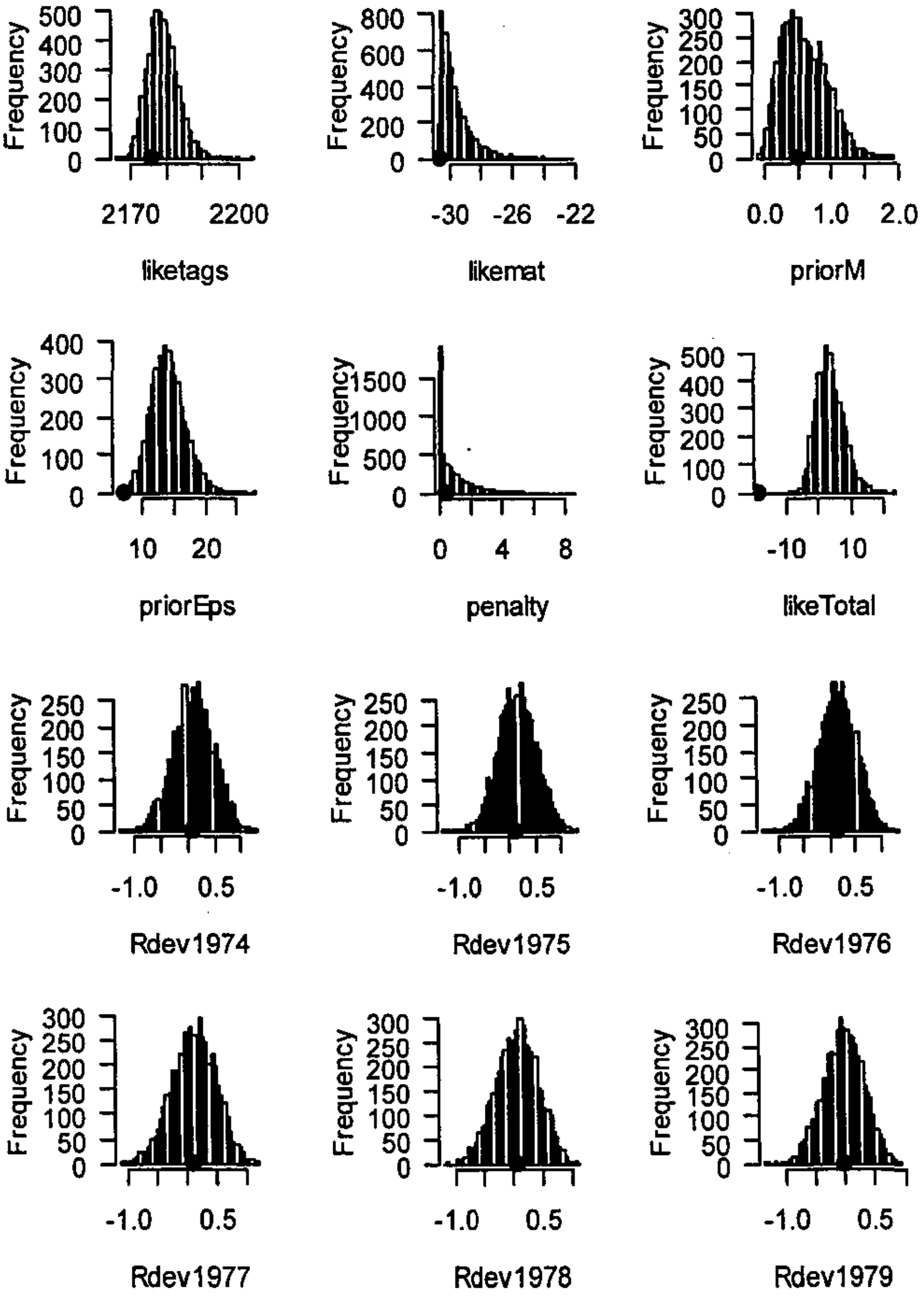

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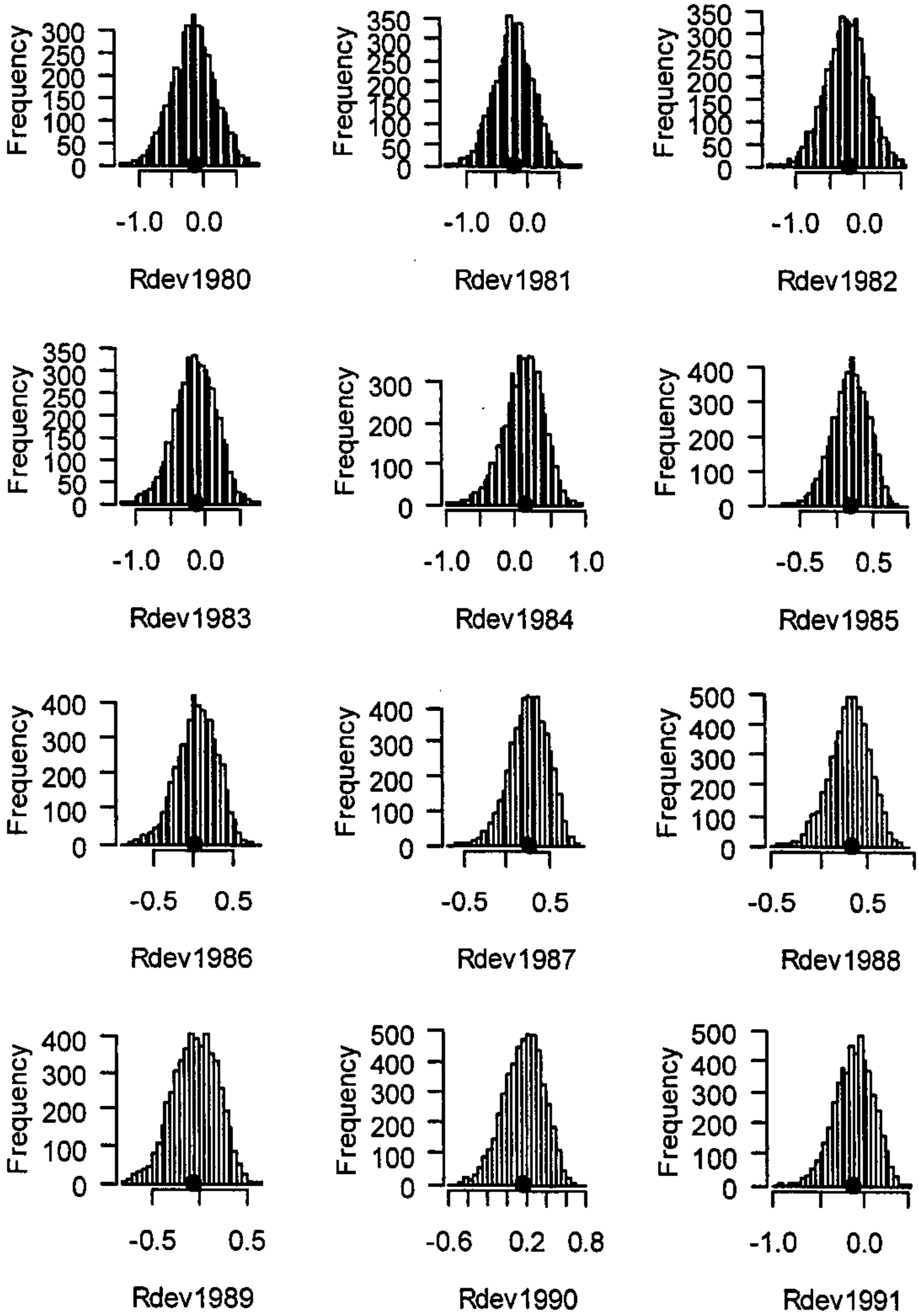

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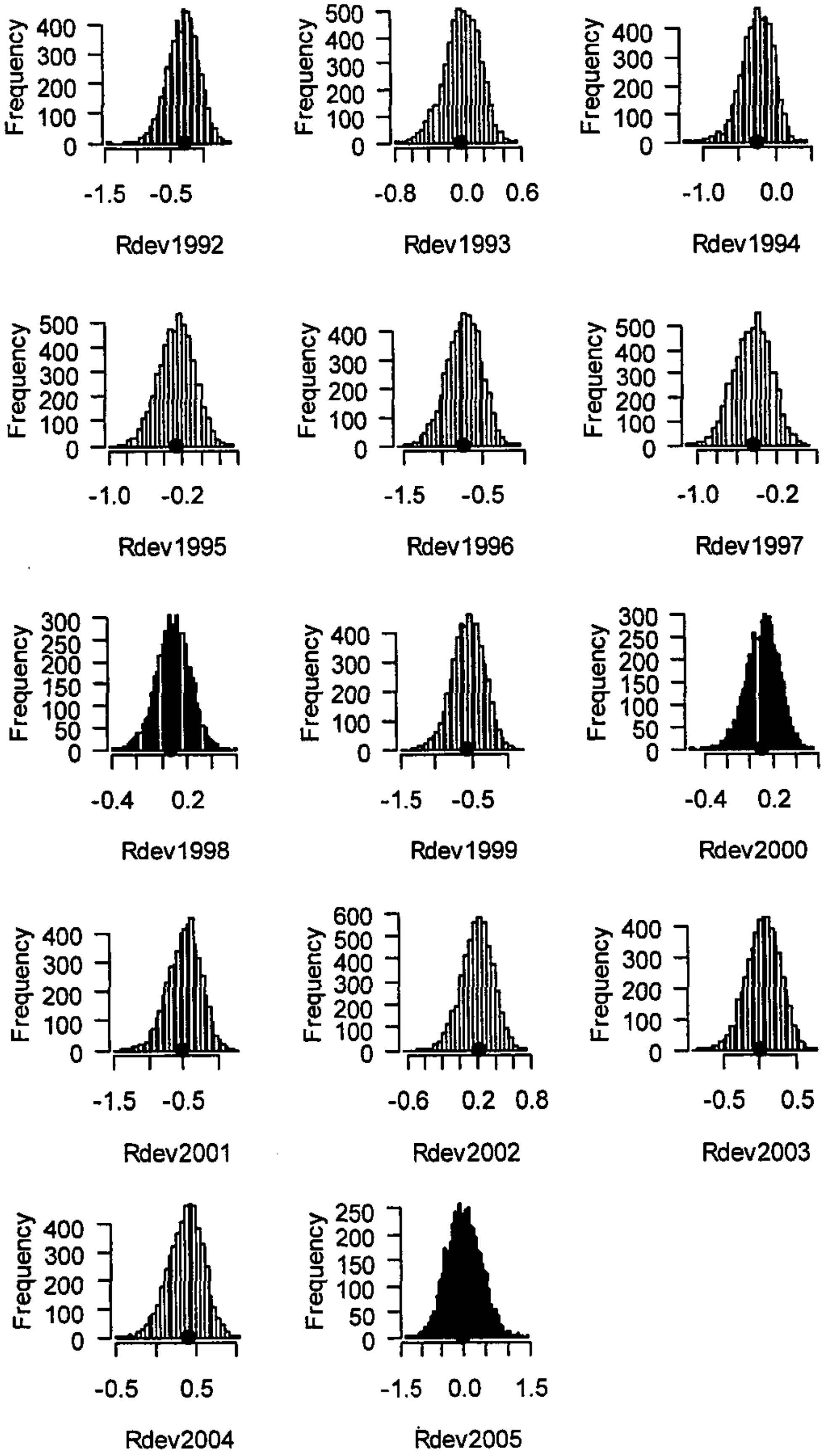


Figure 29: continued.

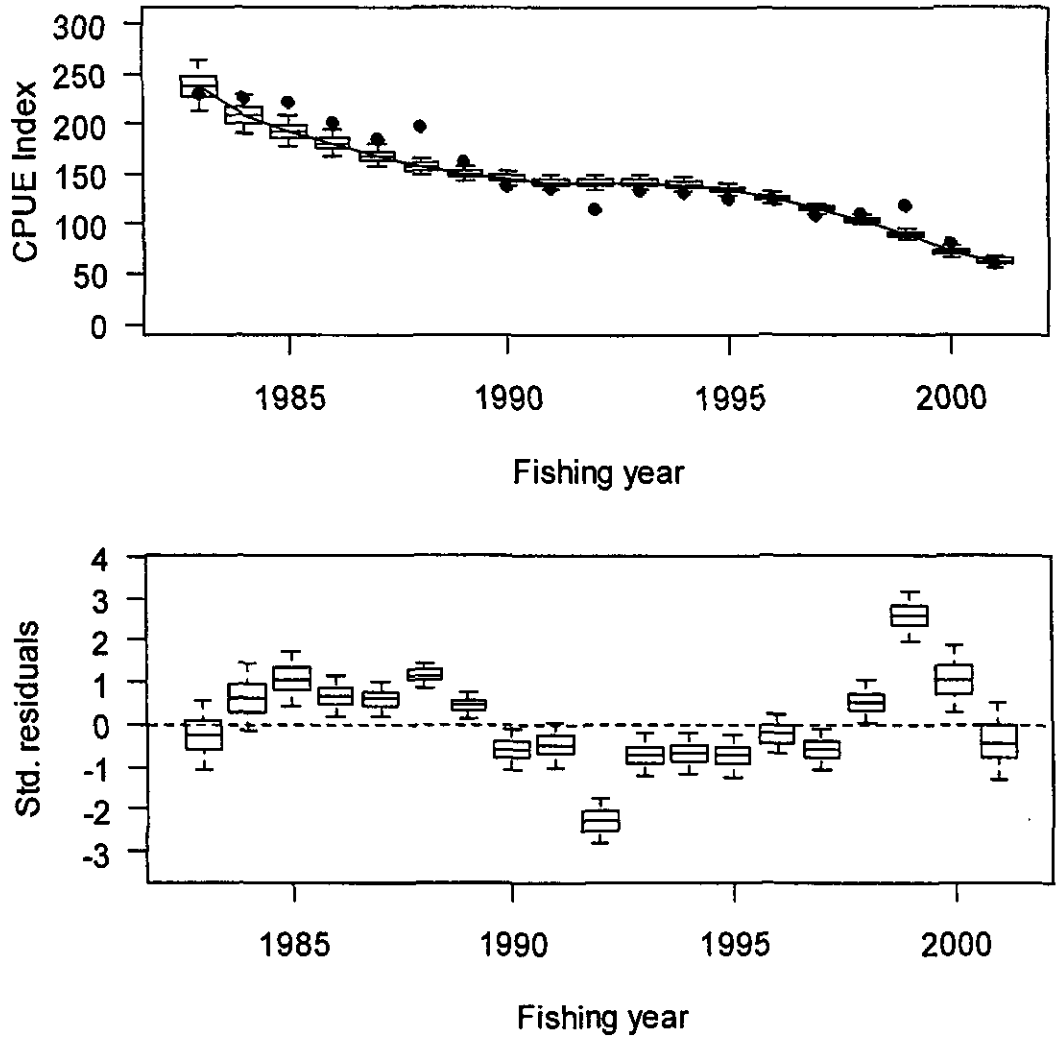


Figure 30: The posterior distributions of the fits to CPUE data (top) and the posterior distributions of the normalised residuals from the base case McMC for PAU 7. In the upper plot, black dots show the observations. For each year, the figure shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box) and 5th and 95th percentiles of the posterior.

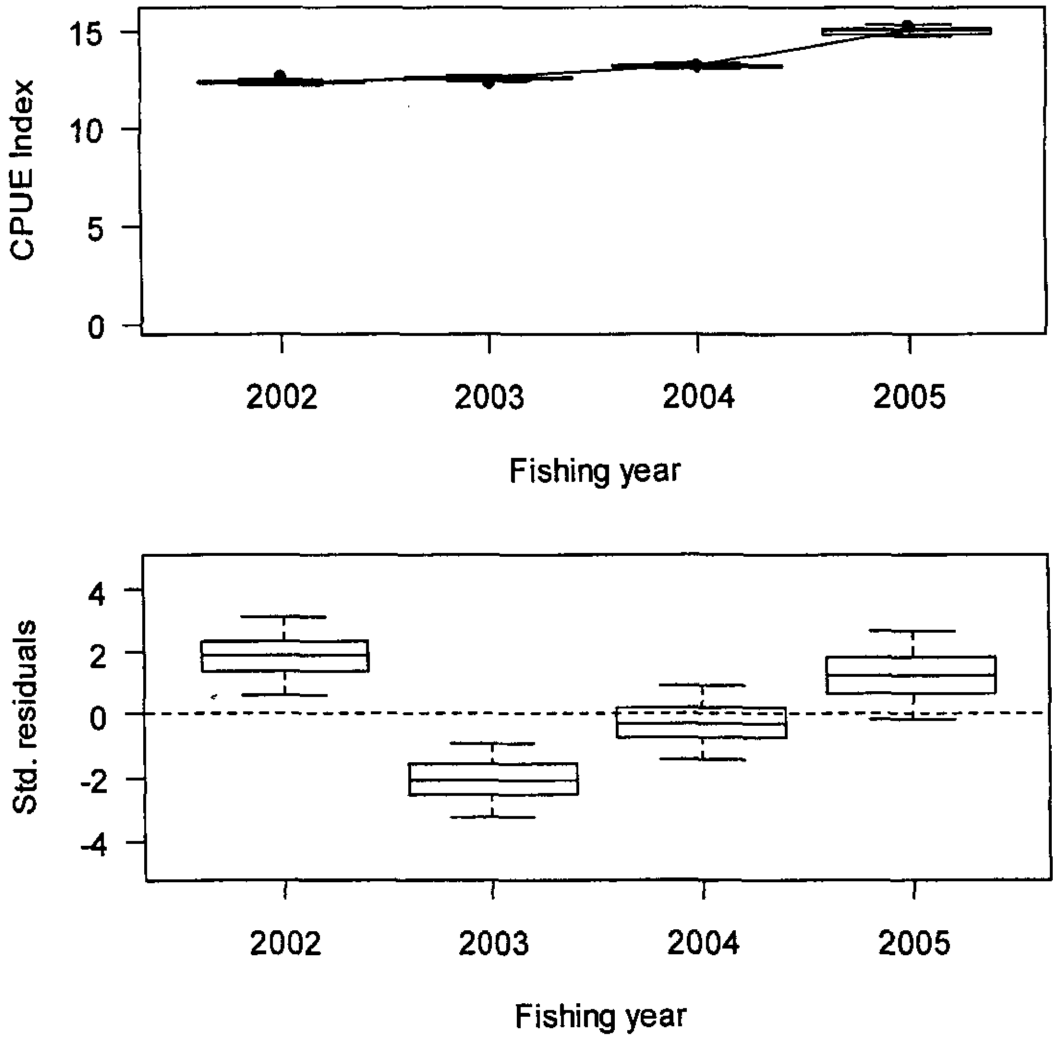


Figure 31: The posterior distributions of the fits to PCPUE data (top) and the posterior distributions of the normalised residuals from the base case McMC for PAU 7. In the upper plot, black dots show the observations. For each year, the figure shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box) and 5th and 95th percentiles of the posterior.

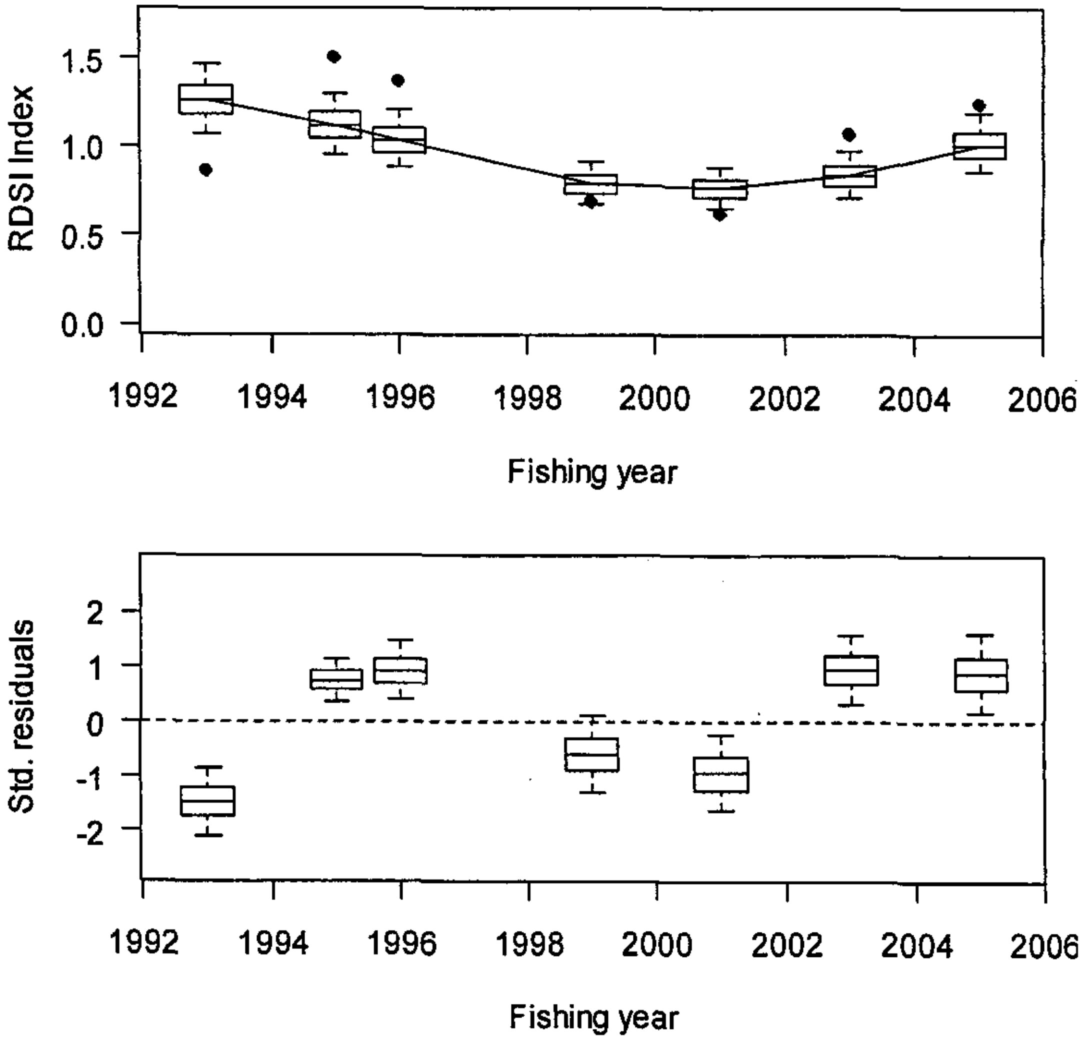


Figure 32: The posterior distributions of the fits to RDSI data (top) and the posterior distributions of the normalised residuals from the base case McMC for PAU 7. In the upper plot, black dots show the observations. For each year, the figure shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box) and 5th and 95th percentiles of the posterior.

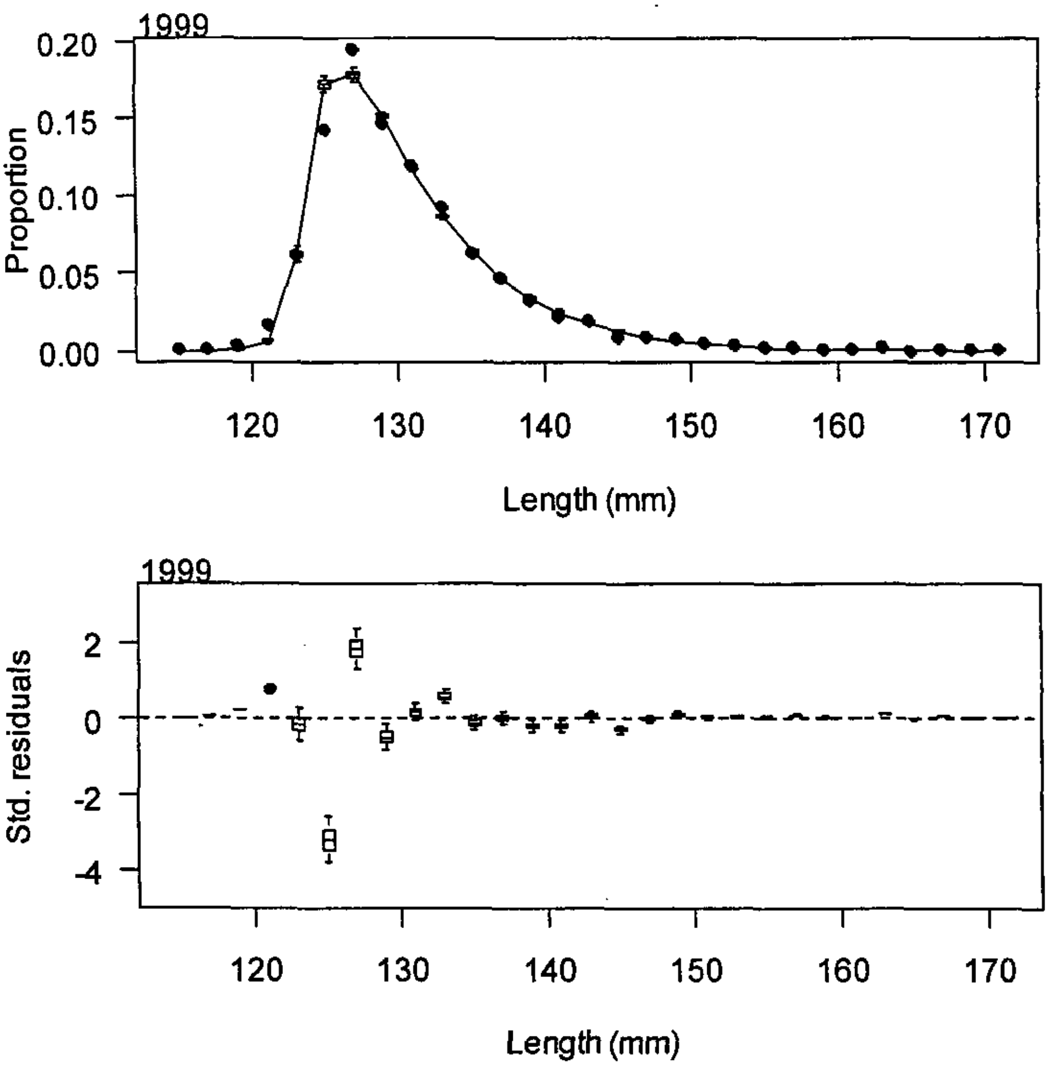


Figure 33: The posterior distribution of the base case McMC fit to the CSLF data from 2002 (top) and the posterior distributions of the normalised residuals.

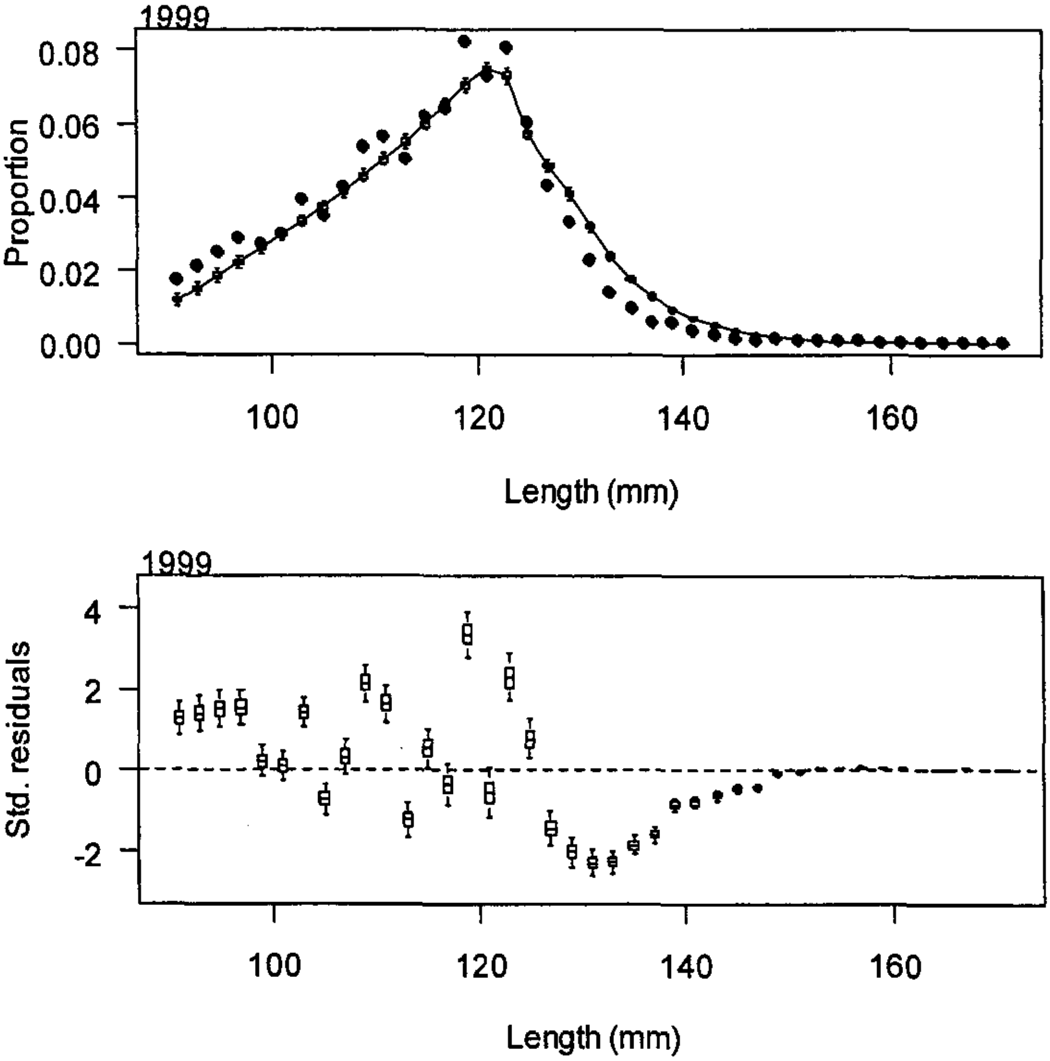


Figure 34: The posterior distributions of the base case McMC fit to the RDLF data from 2002 (top) and the posterior distributions of the normalised residuals.

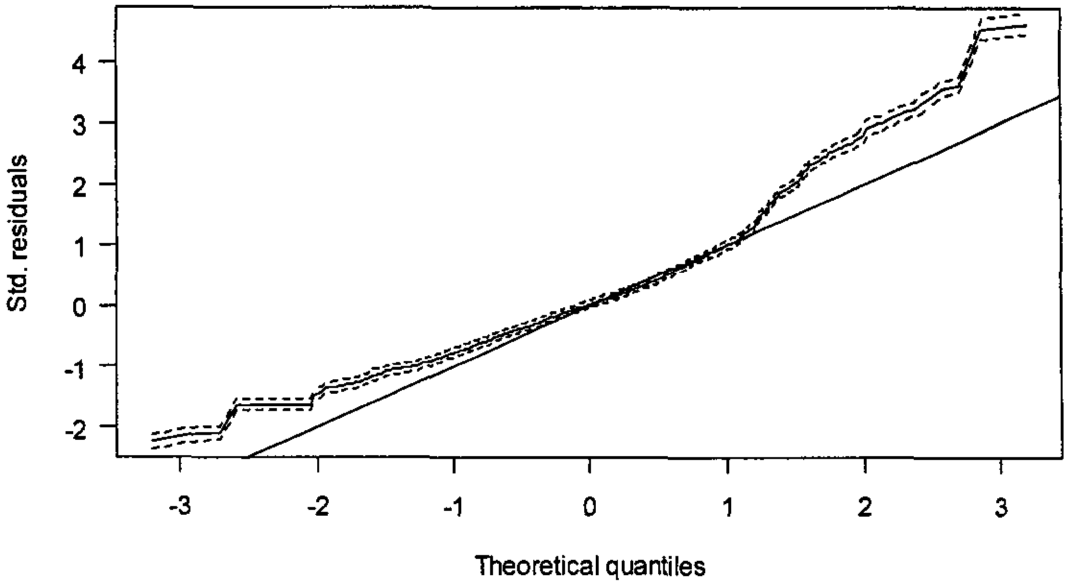


Figure 35: Q-Q plot of the normalised residuals from the posterior distributions of the base case McMC fits to the tag-recapture data.

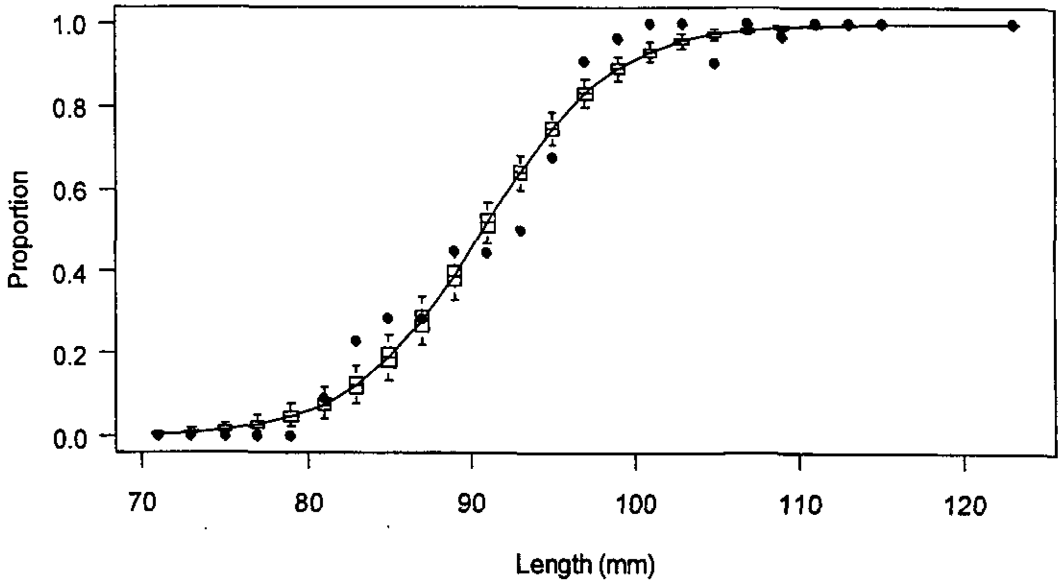


Figure 36: The posterior distribution of the base case McMC fit to maturity-at-length for PAU 7. Dots show the observations and the box plots summarise the posterior as in previous captions.

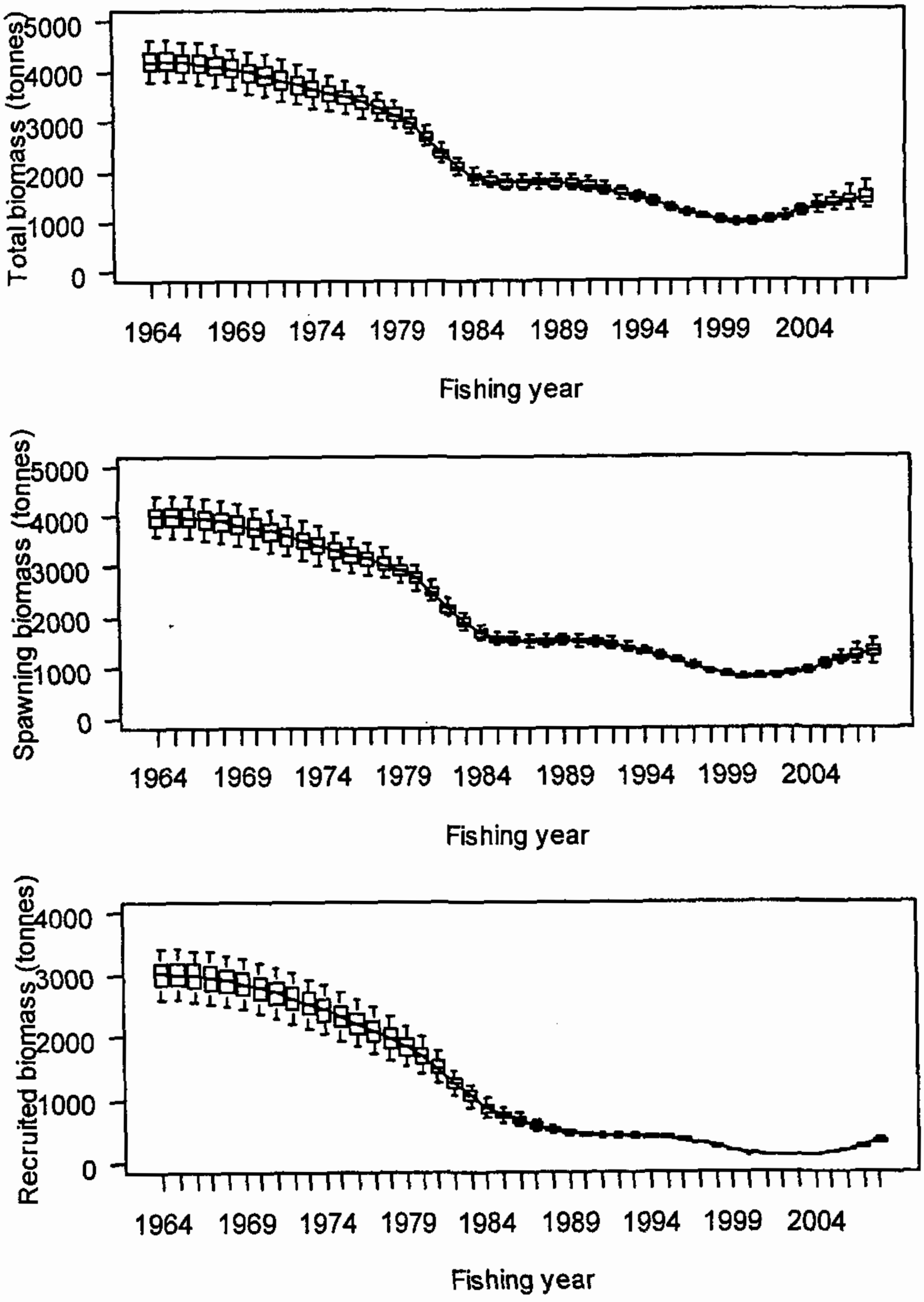


Figure 37: The posterior biomass trajectories from the base case McMC for PAU 7: total biomass (top), spawning biomass (middle) and recruited biomass (bottom). Box plots summarise the posterior distribution for each year as described in previous captions.

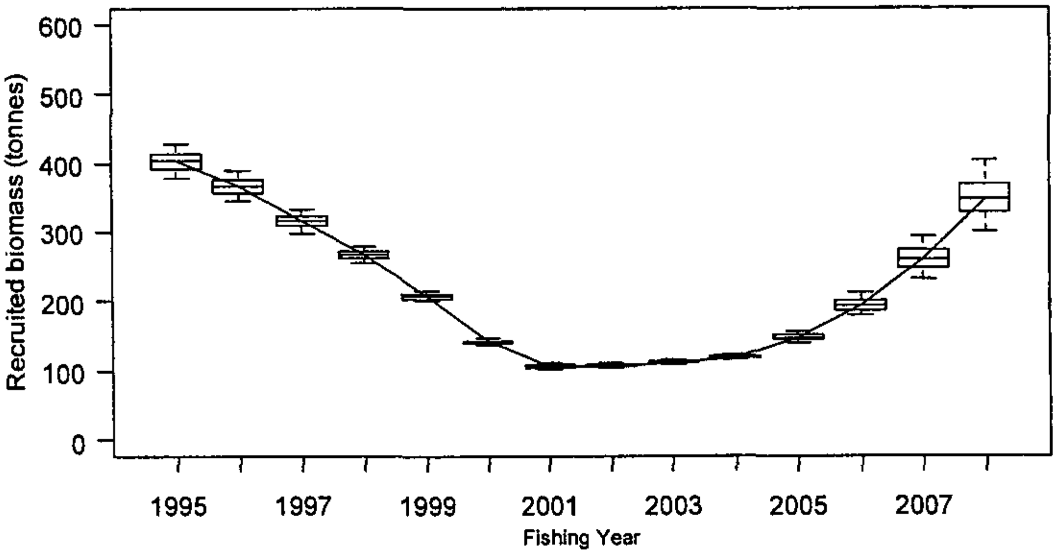
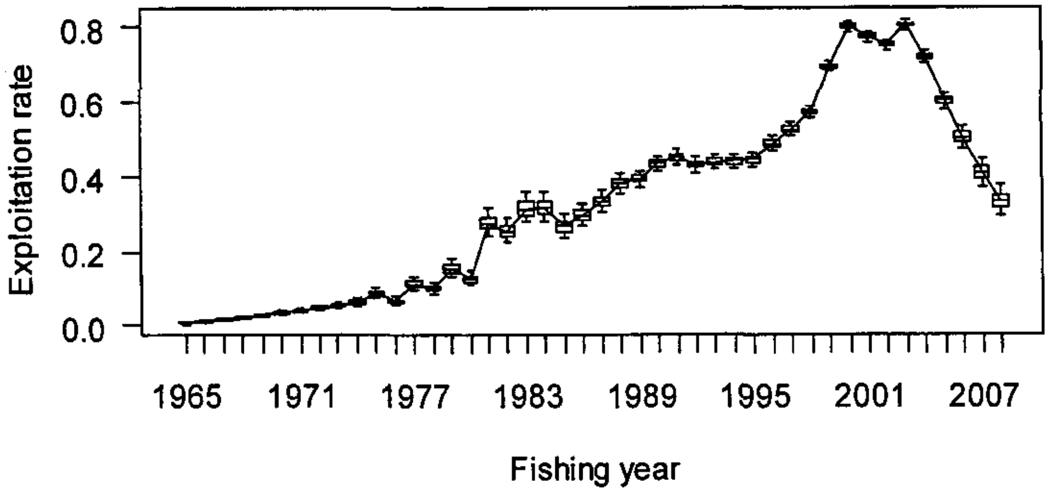


Figure 38: The posterior distribution of the base case McMC recruited biomass trajectory from 1995 onwards.



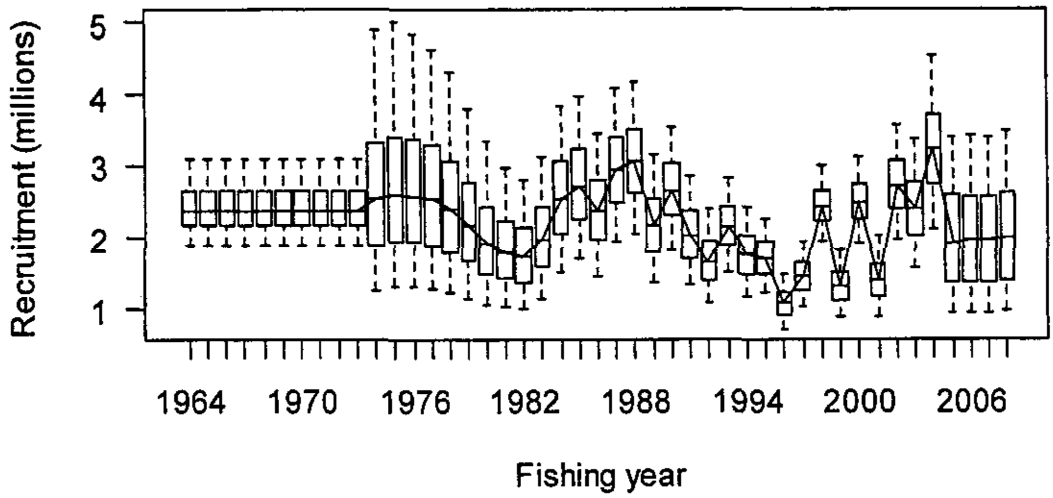


Figure 39: The posterior trajectories of exploitation rate (upper) and recruitment (lower) for the base case McMC for PAU 7.

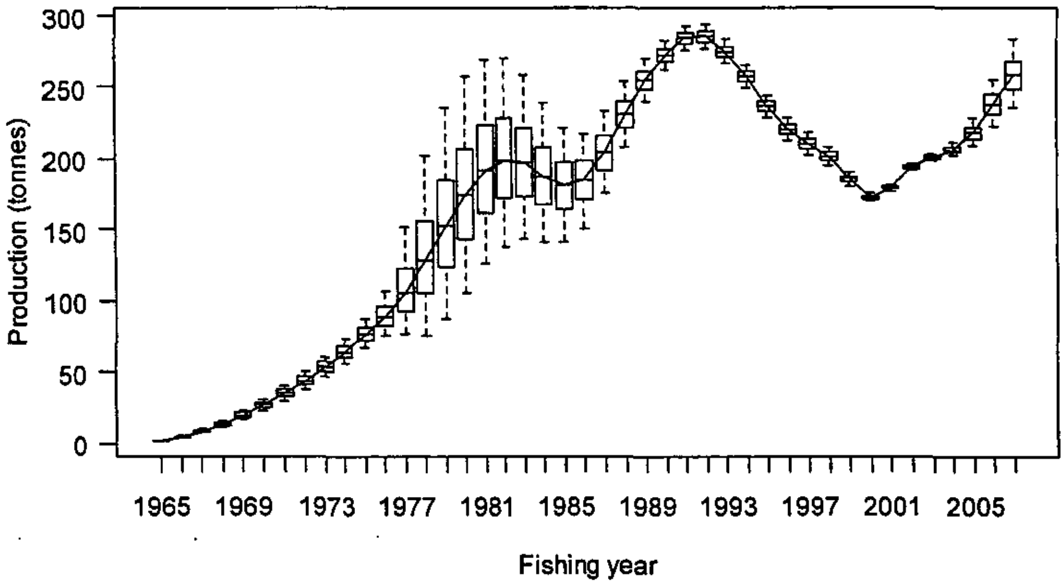


Figure 40: The posterior trajectory of estimated surplus production from the base case McMC for PAU 7.

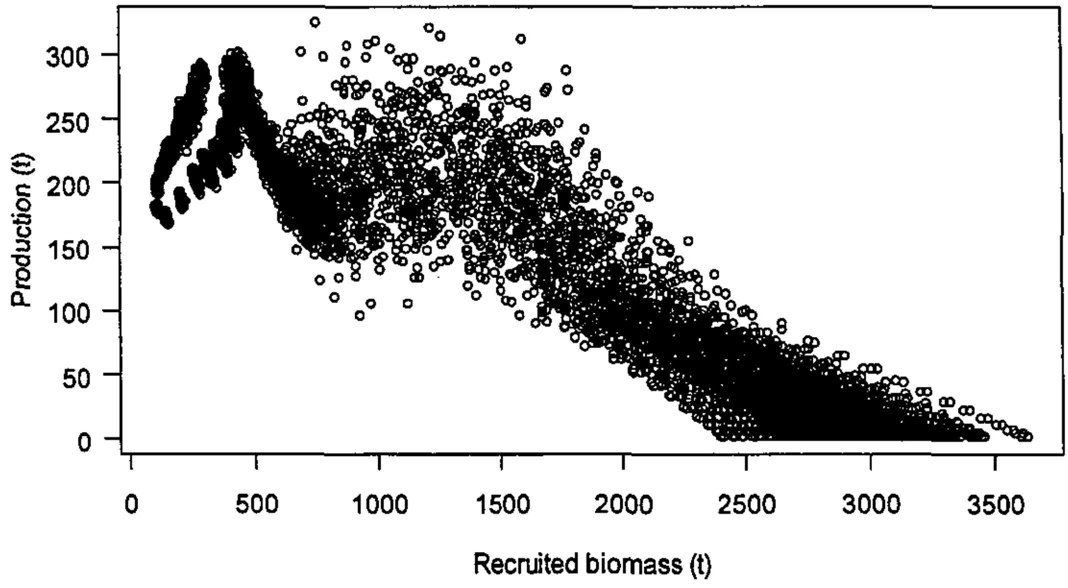


Figure 41: Surplus production plotted against mid-year recruited biomass from the base case McMC for PAU 7. Each point represents one year in one sample from the joint posterior distribution. For this plot, samples were uniformly thinned to 4% of the total sample.

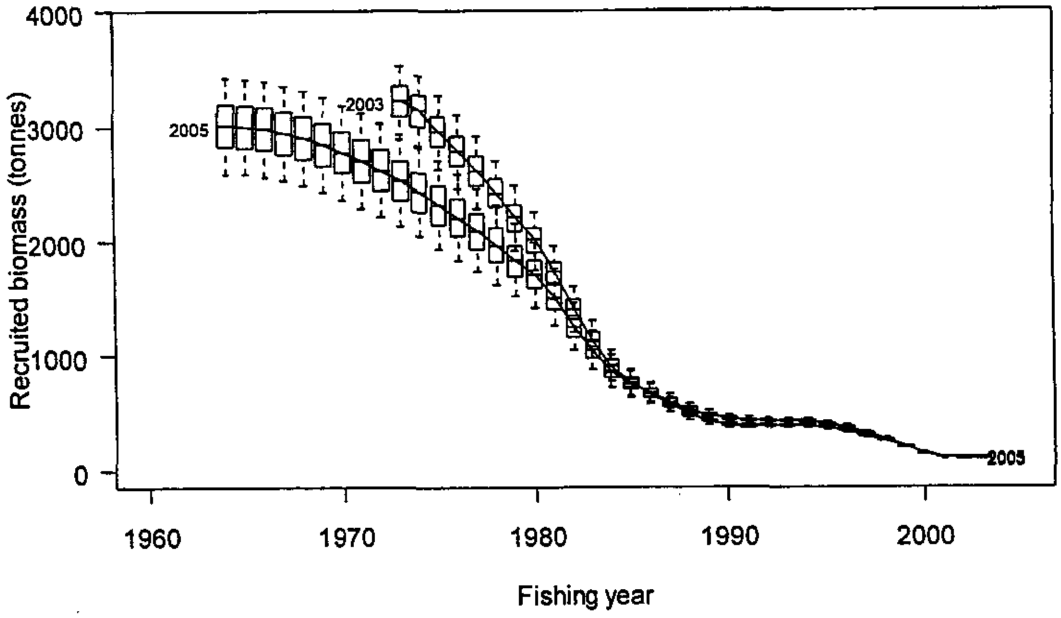


Figure 42: Comparison of recruited biomass from the 2003 and 2005 stock assessments.

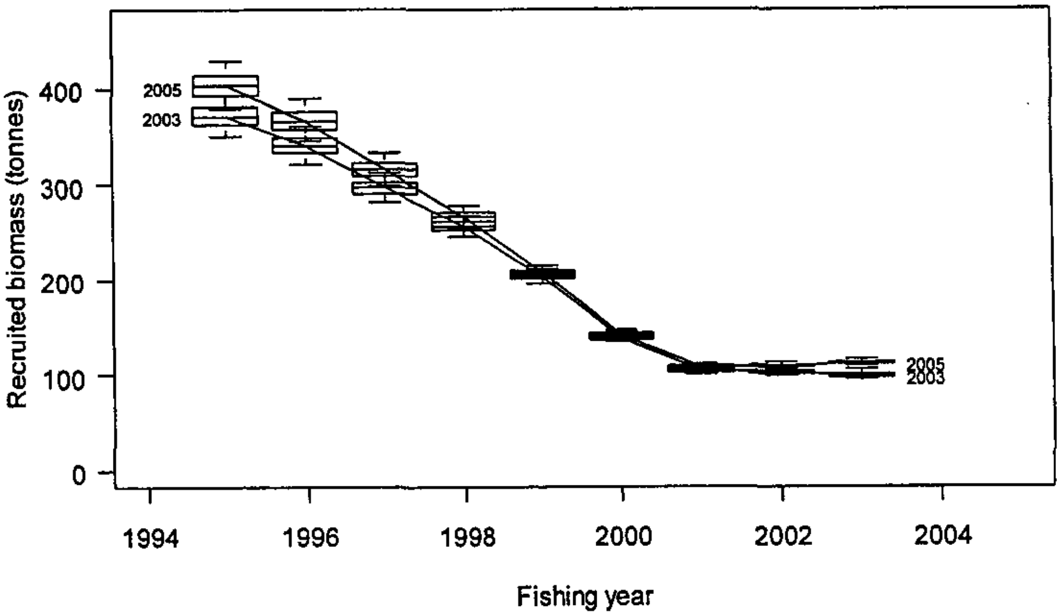


Figure 43: Comparison of recruited biomass from the 2003 and 2005 stock assessments from 1995-2003.

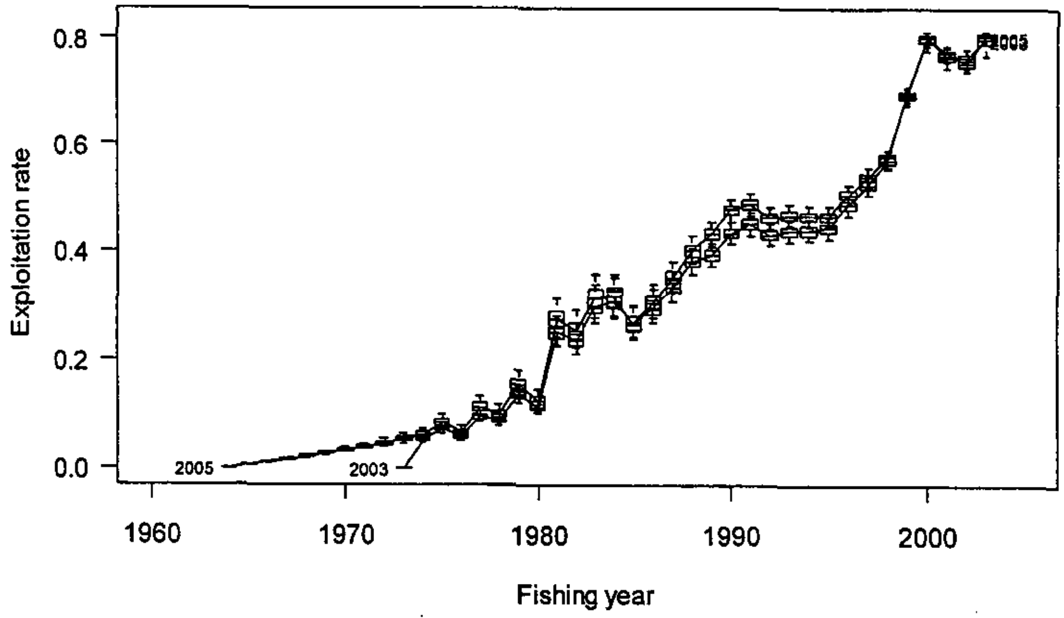


Figure 44: Comparison of exploitation rate from the 2003 and 2005 stock assessments.

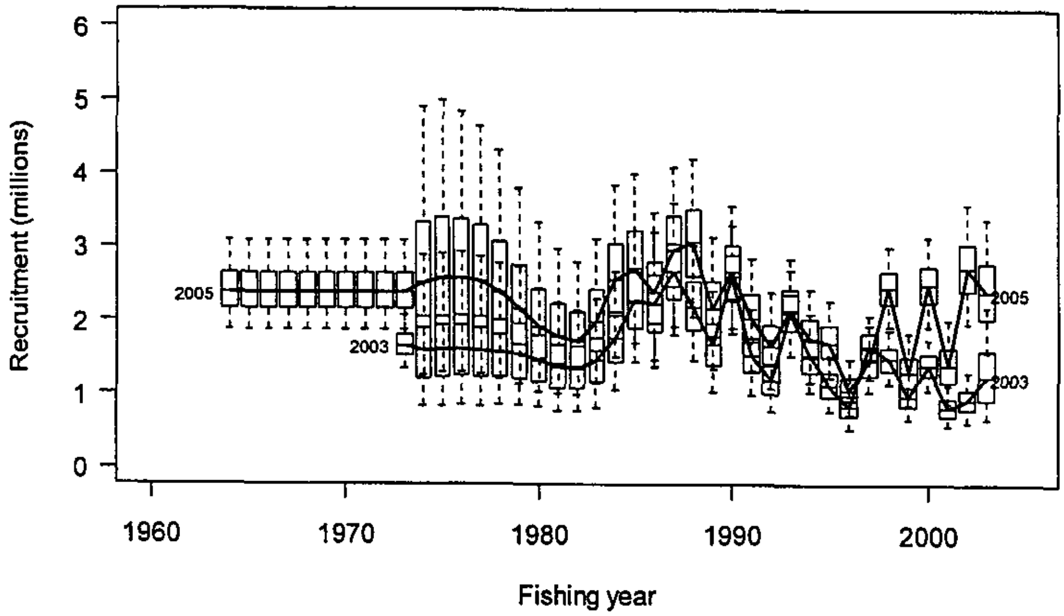


Figure 45: Comparison of recruitment from the 2003 and 2005 stock assessments.

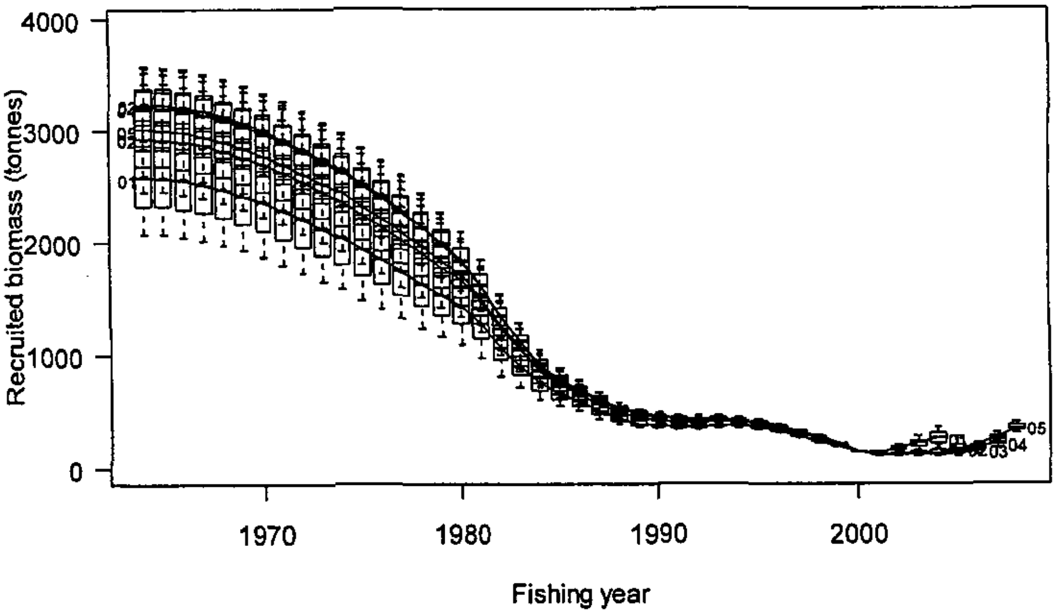


Figure 46: The posterior trajectories of recruited biomass from the McMC retrospective sensitivity trials for PAU 7. Labels indicate the last year of data used, thus "05" is the base case.

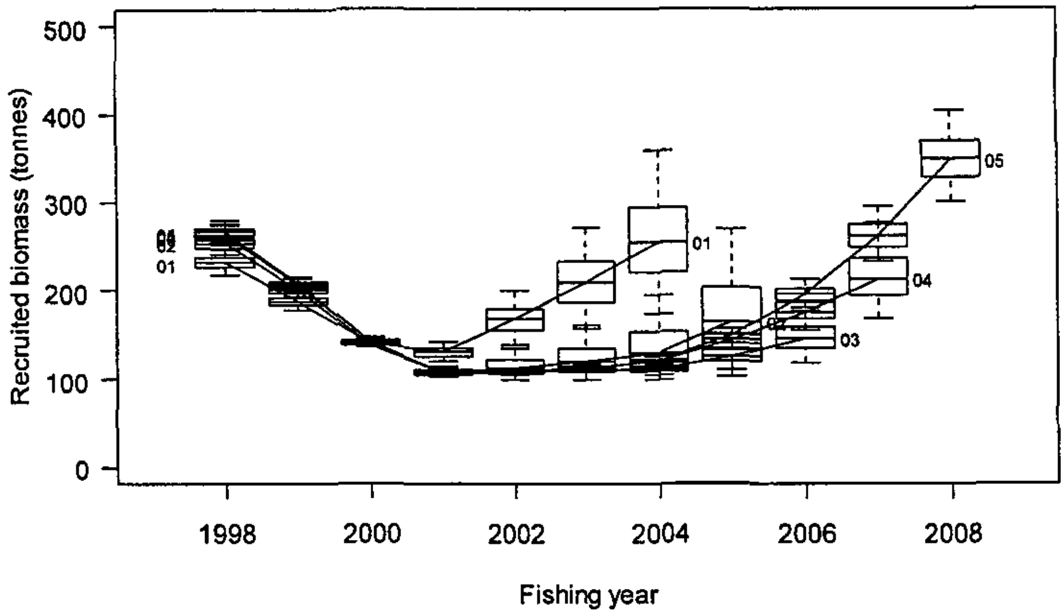


Figure 47: For 1998 onwards, the posterior trajectories of recruited biomass from the McMC retrospective sensitivity trials for PAU 7. Labels indicate the last year of data used, thus "05" is the base case.

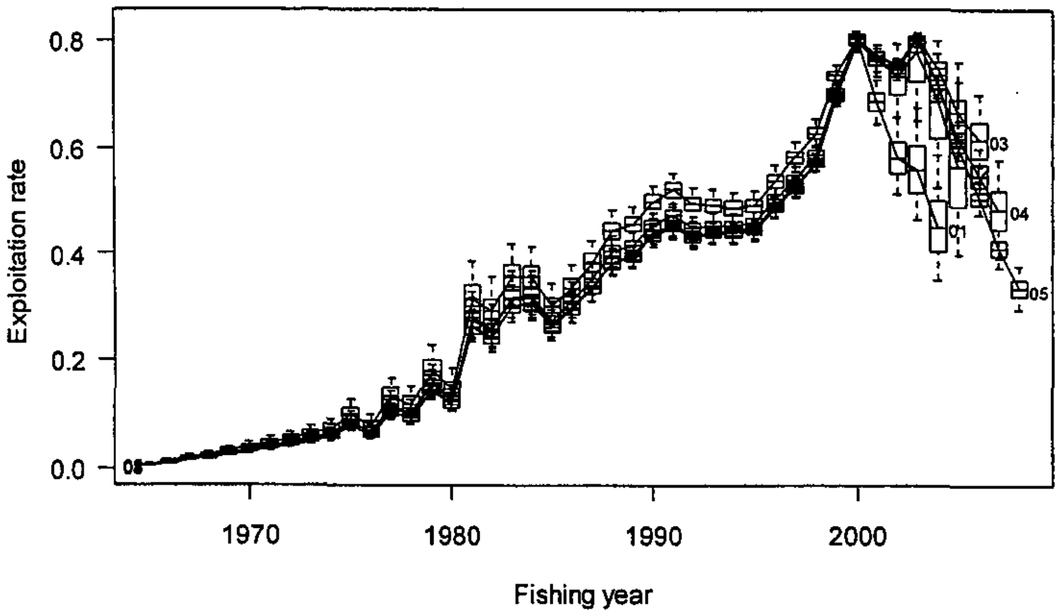


Figure 48: The posterior trajectories of exploitation rate from the McMC retrospective sensitivity trials for PAU 7. Labels indicate the last year of data used, thus "05" is the base case.

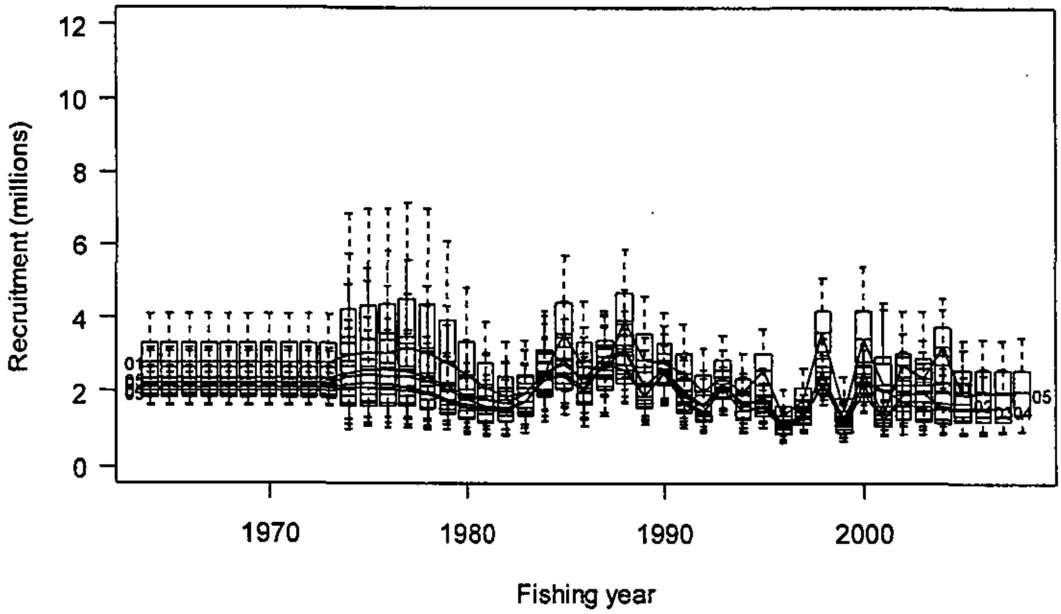


Figure 49: The posterior trajectories of recruitment from the McMC retrospective sensitivity trials for PAU 7. Labels indicate the last year of data used, thus "05" is the base case.

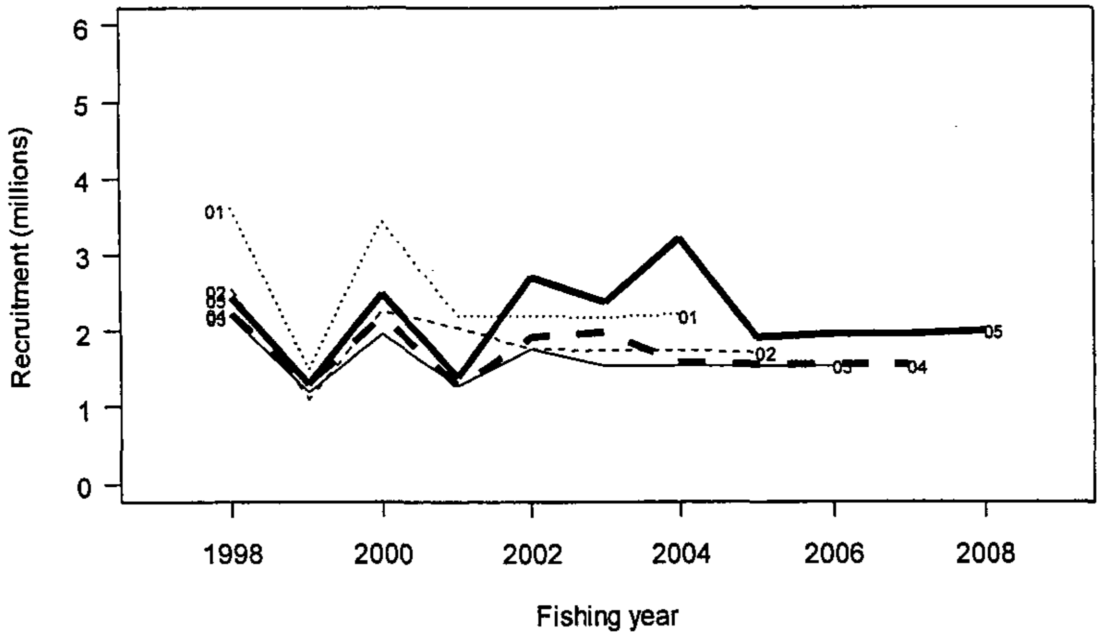


Figure 50: The medians of posterior trajectories of recruitment from the McMC retrospective sensitivity trials for 1998 to 2005. Labels indicate the last year of data used, thus "05" is the base case.

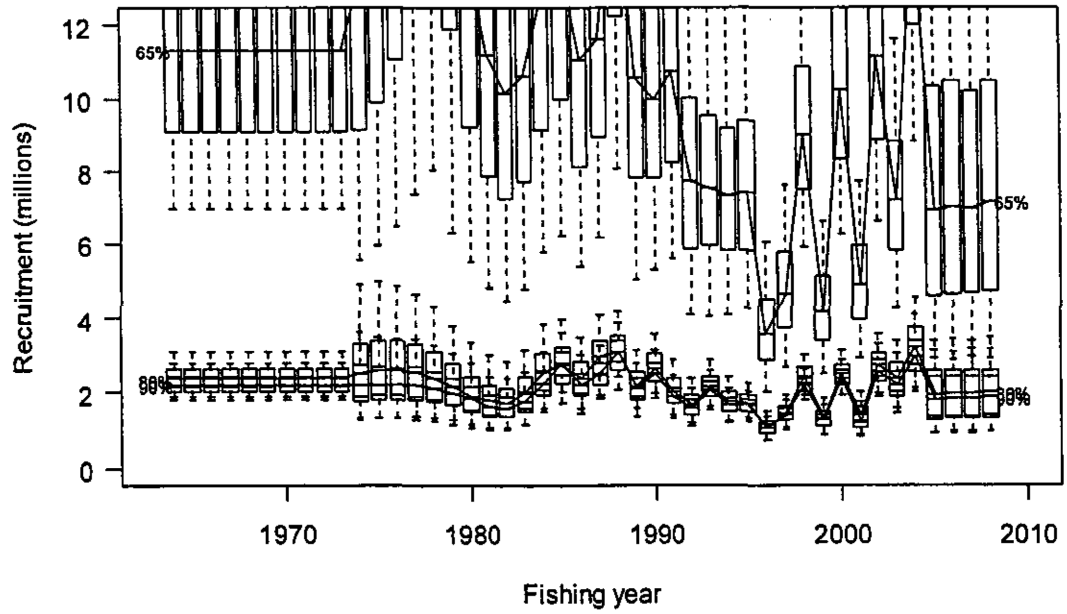


Figure 51: Posteriors of recruitment trajectories from the McMC sensitivity trials in which maximum allowed exploitation rate was varied from 80% in the base case to 65% and 90%. The 65% trial is the highest set of box plots.

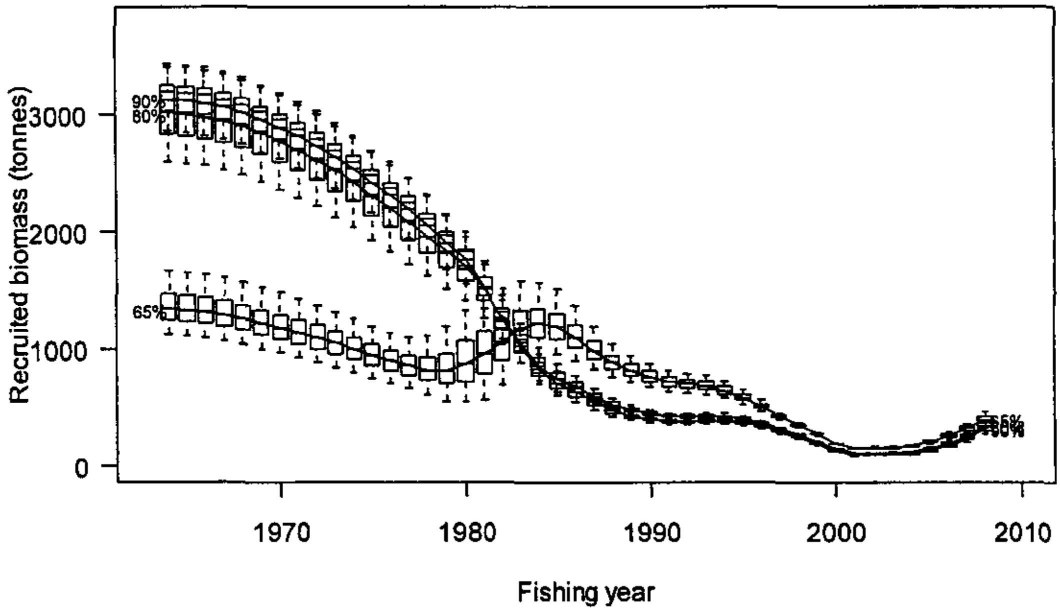


Figure 52: Recruited biomass trajectories from the McMC sensitivity trials in which maximum allowed exploitation rate was varied from 80% in the base case to 65% and 90%. The 65% trial is the line that is lowest on the left and highest in the early 2000s.

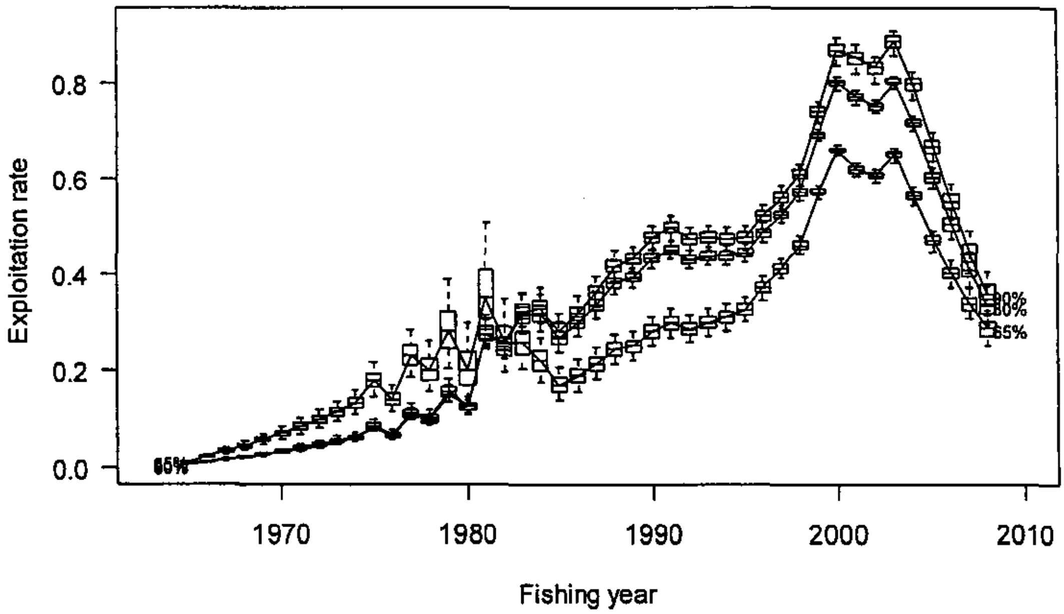


Figure 53: Posteriors of exploitation rate from the McMC sensitivity trials in which maximum allowed exploitation rate was varied from 80% in the base case to 65% and 90%. The 65% trial is the lowest set of box plots.

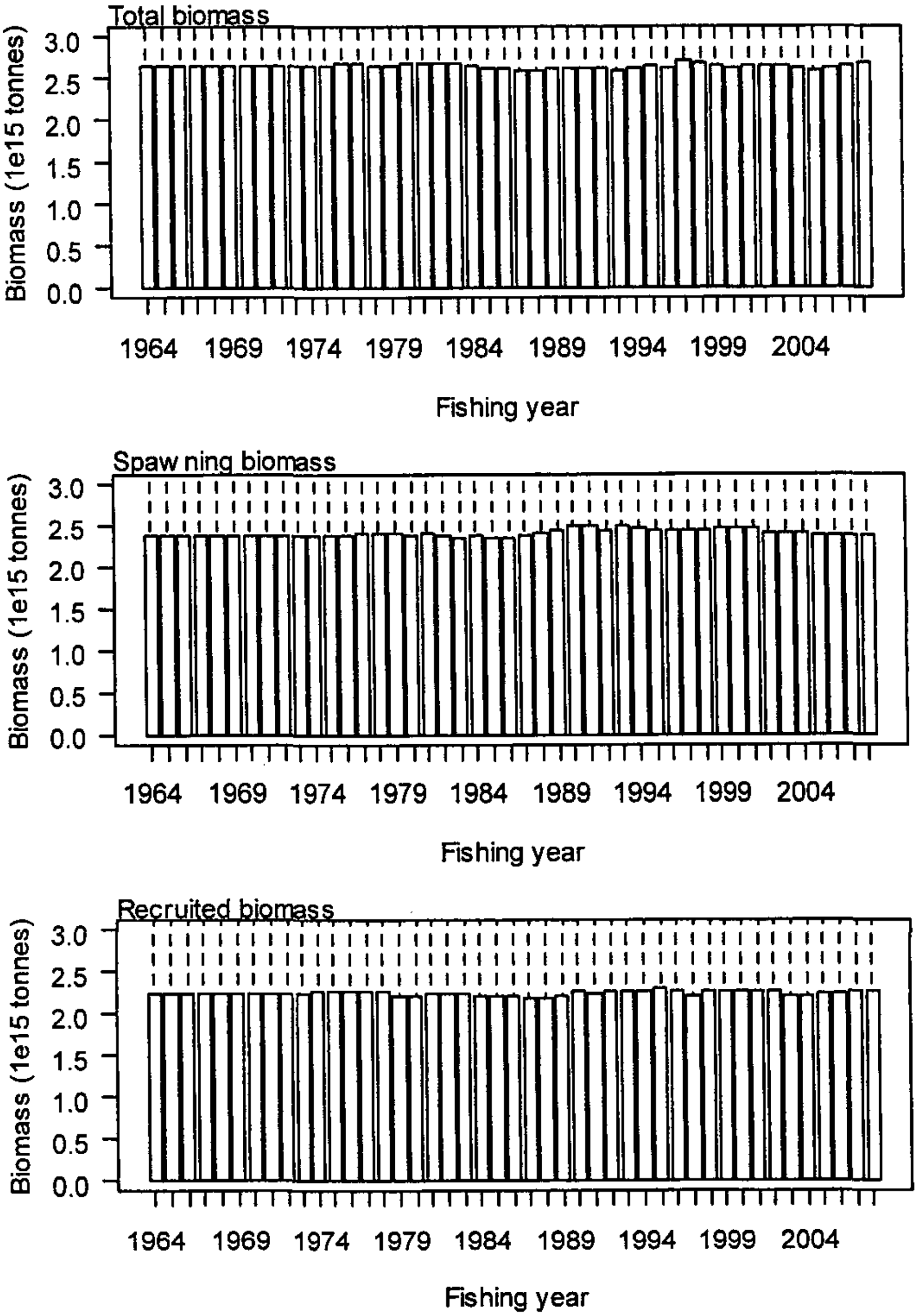


Figure 54: Posterior trajectories of recruited biomass from the "implicit prior" McMC sensitivity trial.

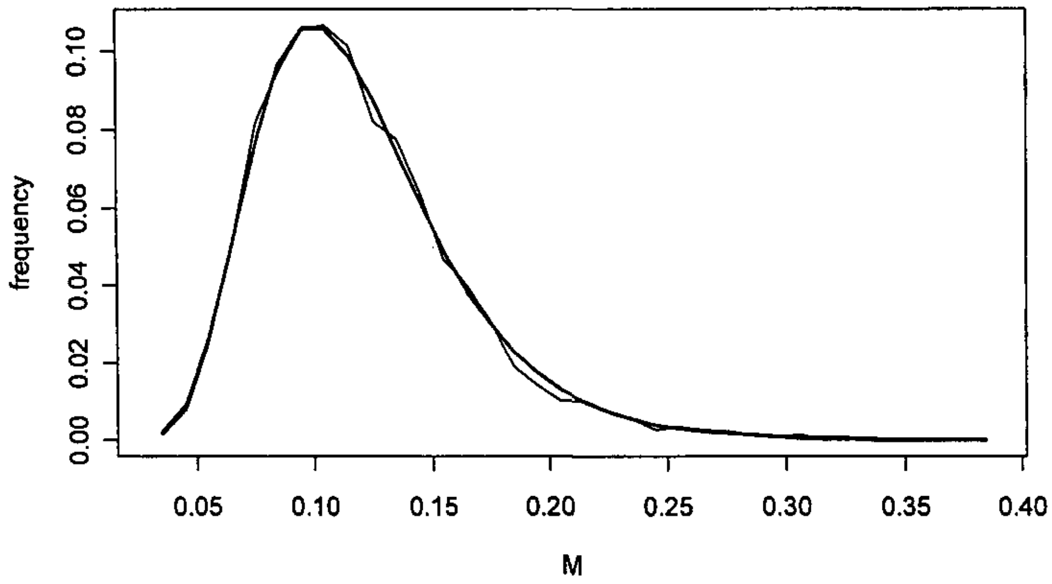


Figure 55: The posterior distribution of M (thin black line) compared with the prior distribution (grey line) from the "implicit prior" McMC sensitivity trial.

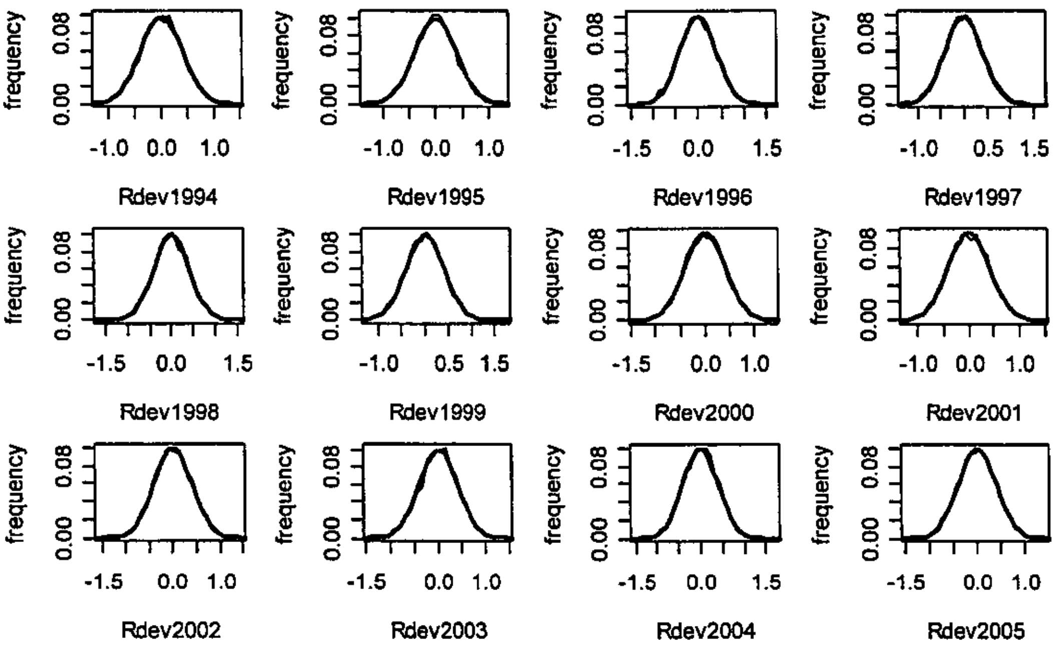


Figure 56: The posterior distribution of recruitment deviations for years 1994-2005 (thin black line almost entirely hidden behind the other) compared with the prior distribution (grey line) from the "implicit prior" McMC sensitivity trial. Deviations from 1974-93 were identical to these.

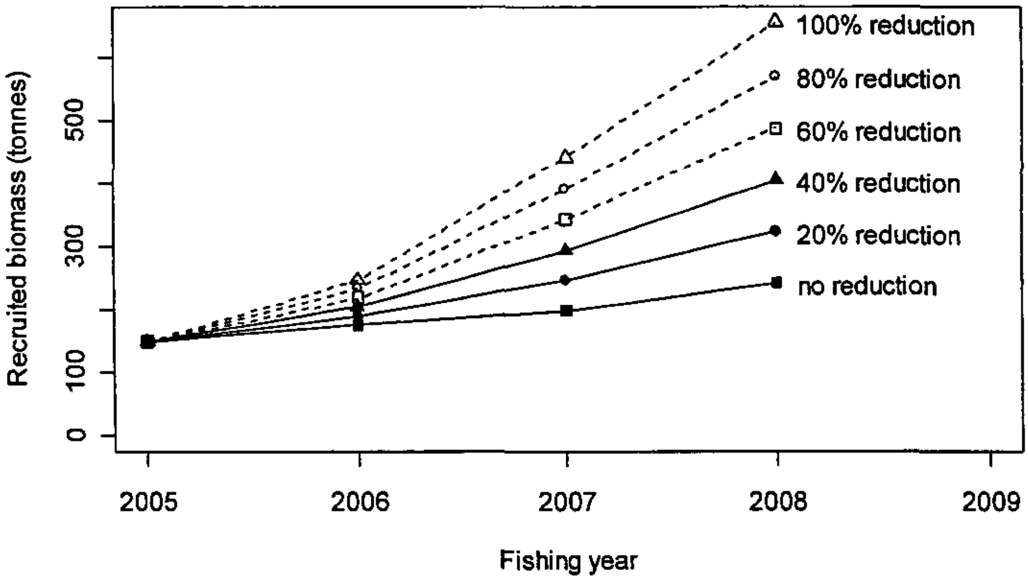


Figure 57: Medians of the posteriors of recruited biomass trajectories from the alternative catch projections based on the base case McMC for PAU 7. The sets of projections illustrated are a subset of the full range made (see Table 3).

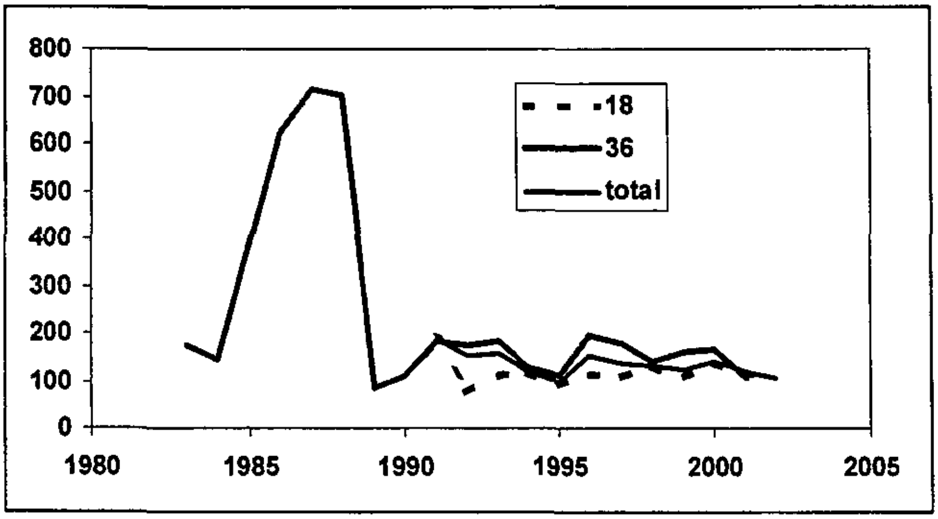


Figure 58: CPUE (kg per diver day) from CELRs in areas 18 and 36.

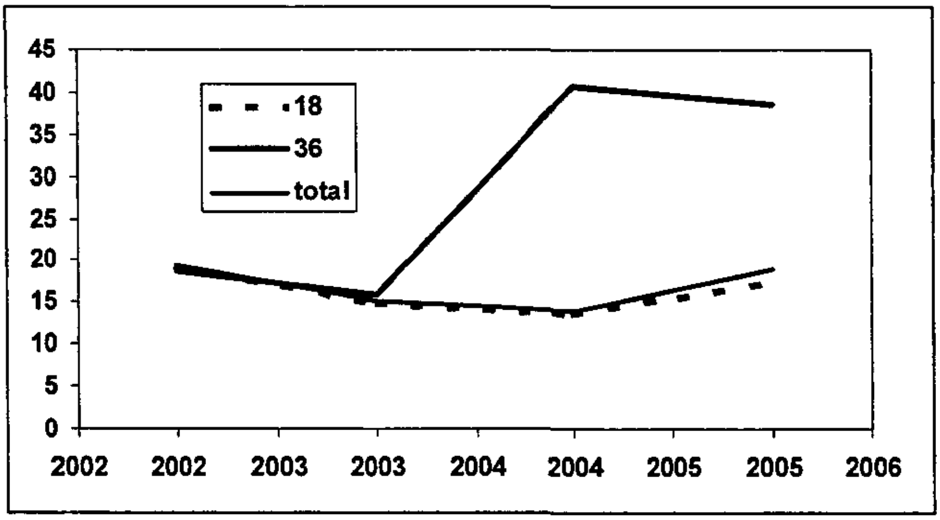


Figure 59: PCPUE (kg per diver hour) from PCELRs in areas 18 and 36.

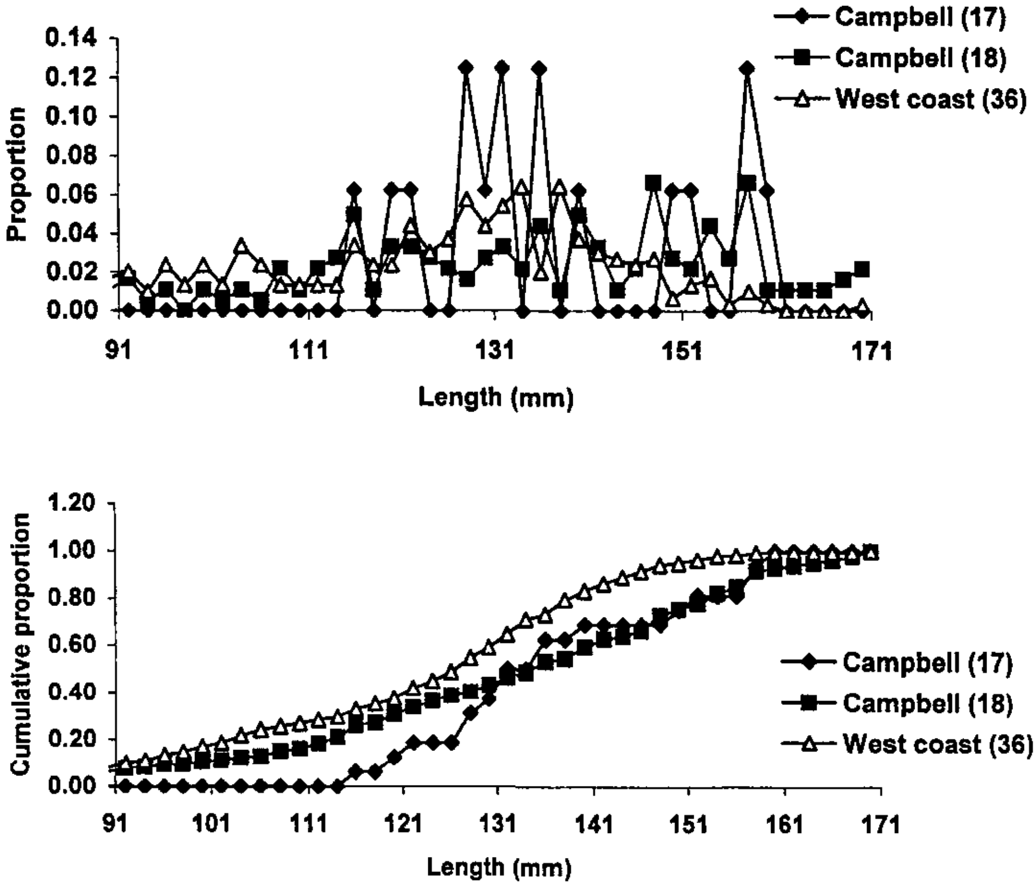
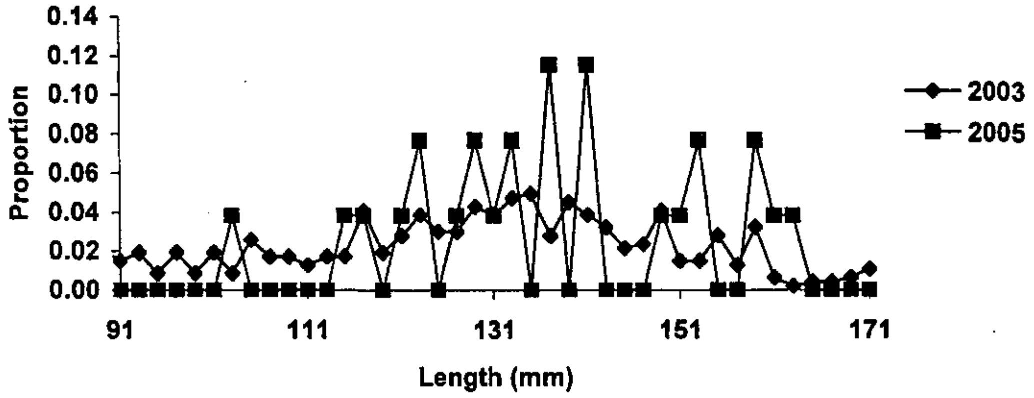


Figure 60: RDLFs by stratum for areas 18 and 36, plus some "Campbell" data from area 17; shown as proportions-at-length (upper) and cumulative proportion (lower).



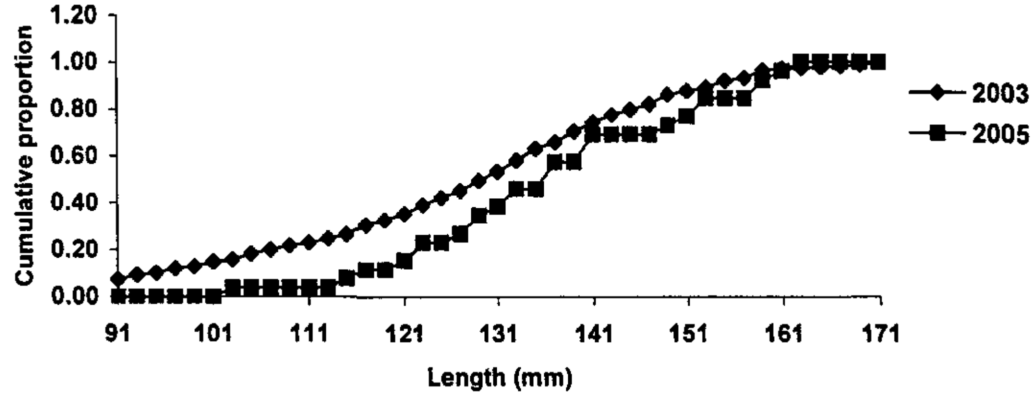


Figure 61: RDLF data from for areas 18 and 36, plus some "Campbell" data from area 17, for each of the two survey years (see Table 36).

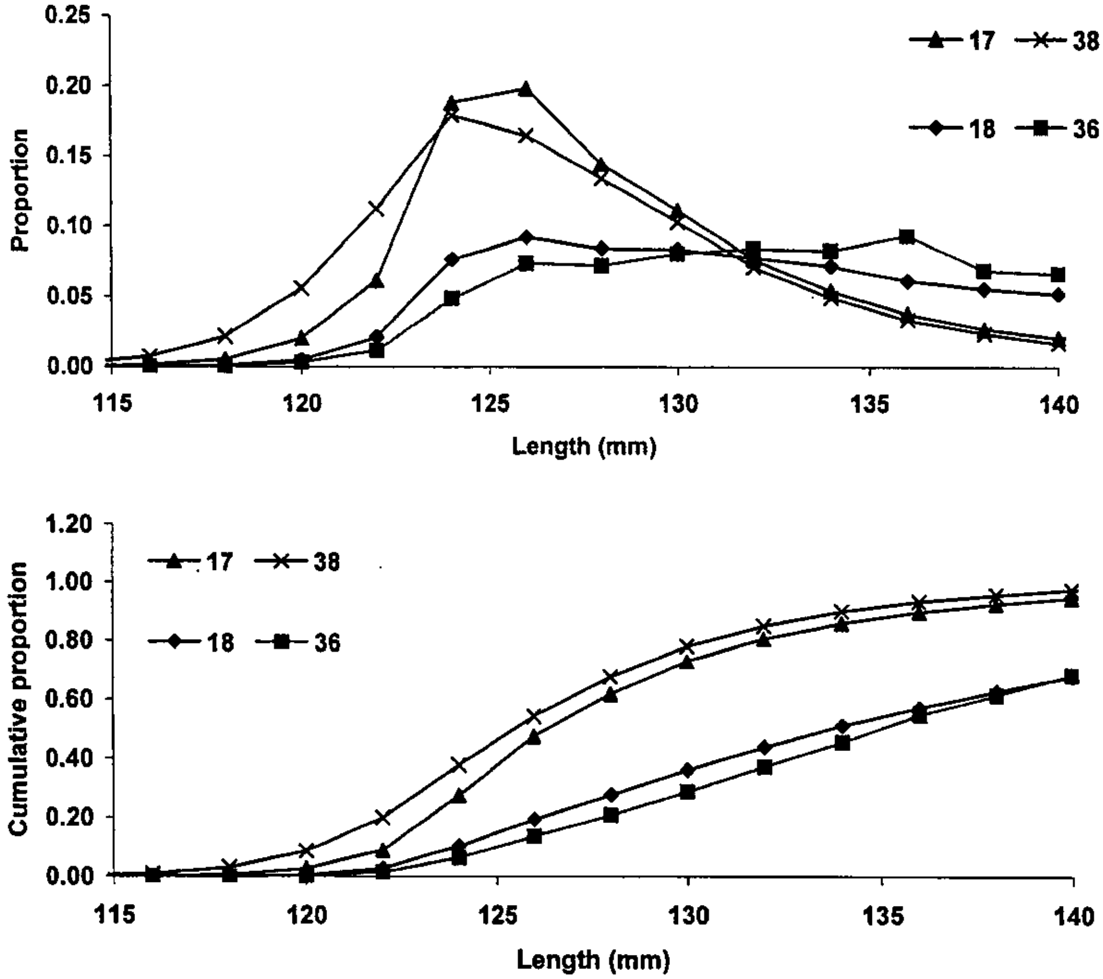
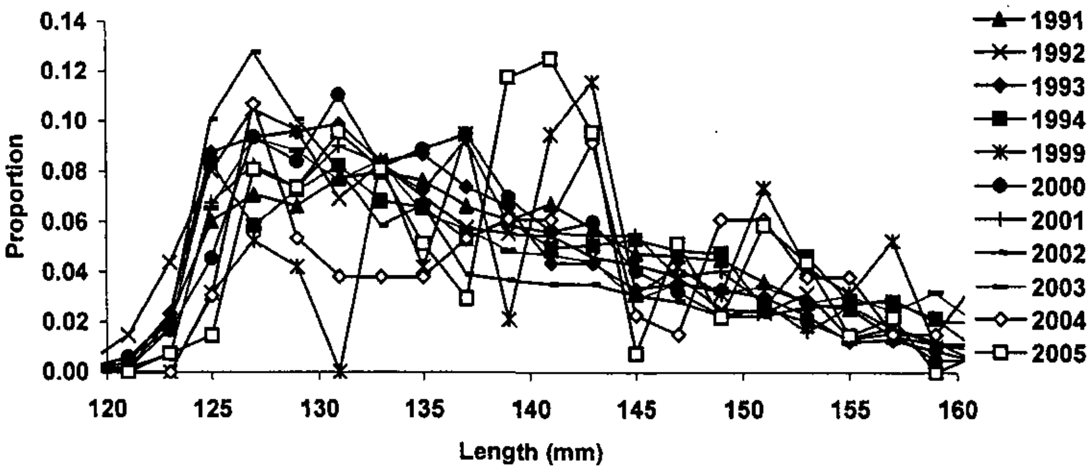


Figure 62: CSLF data by statistical area in PAU 7.



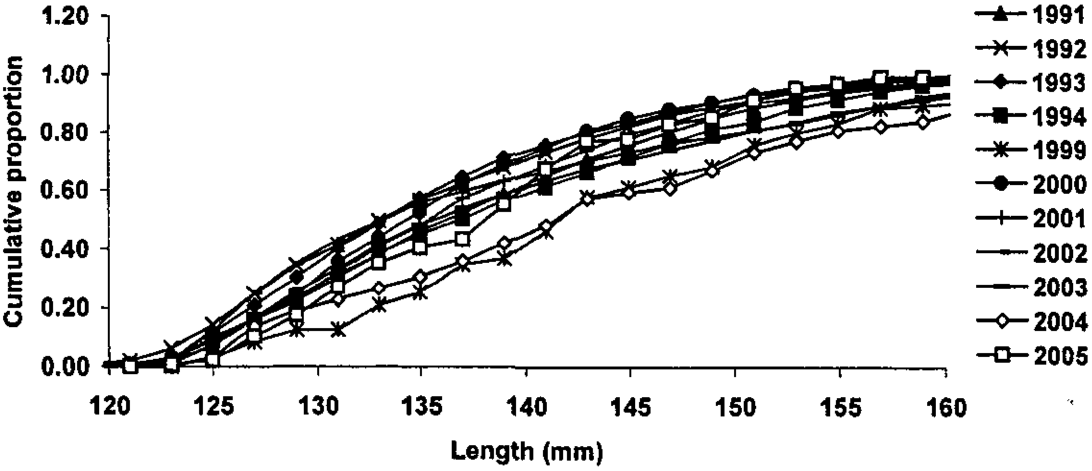


Figure 63: CSLF data from areas 18 and 36 combined, plotted by fishing year.

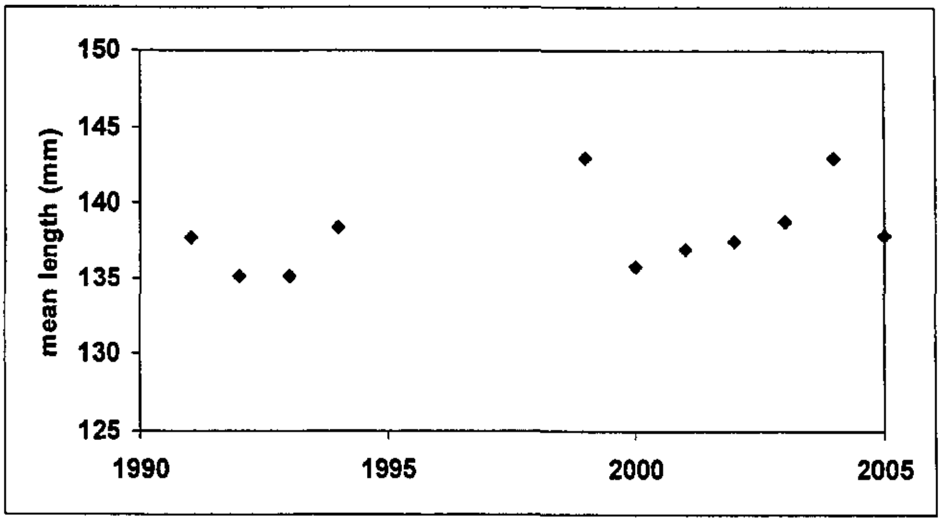


Figure 64: Mean length from CSLF data in areas 18 and 36 combined.

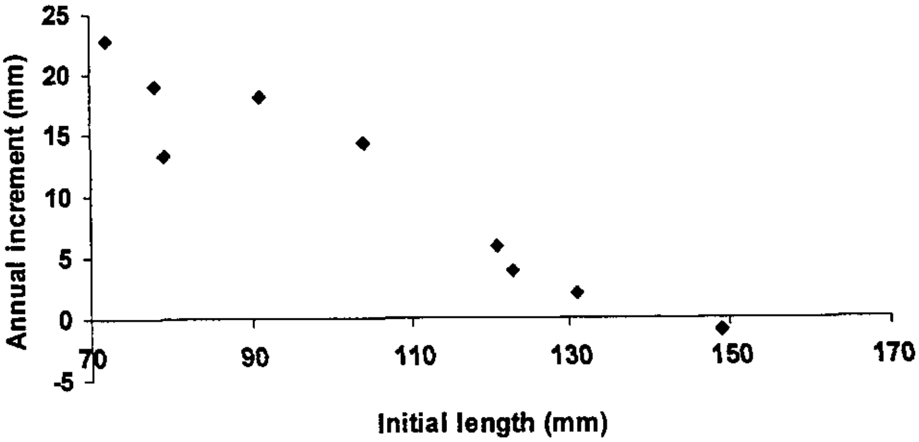


Figure 65: Annual increments from tag-recapture data at Cape Campbell.