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(*Metanephrops challengeri*) in the Bay of Plenty (QMA 1)**

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## EXECUTIVE SUMMARY

Cryer, M.; Dunn, A.; Hartill, B. (2005). Length-based population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (QMA 1). *New Zealand Fisheries Assessment Report 2005/27*. 55 p.

This report outlines a Bayesian, length-based, two-sex population model for scampi (*Metanephrops challengeri*) in the Bay of Plenty (QMA 1) up to the end of the 2002–03 fishing year. Initial development of the model was reported in a Research Progress Report by the same authors and discussed in some detail by the Shellfish Fishery Assessment Working Group (SFAWG) in March 2004. We describe the available data and parameterisation of the model, and present fits, diagnostic plots, and model estimates, including Markov chain Monte Carlo (MCMC) estimates of posterior distributions. The model is offered as a basis for discussion (rather than as firm evidence of the current status of the stock) because this is the first attempt at developing a length-based population model for any stock of scampi, and represents a substantially different approach from stock assessments conducted on related species overseas.

The model is Bayesian and length-based and is implemented using the general-purpose stock assessment software CASAL v2.06 (September 2004). The model offered as a base model represents some of the data reasonably well, but does not faithfully represent commercial or research trawl catch-effort data, nor the observed marked changes in sex ratio. Abundance indices and estimated sex ratios from trawl catch rates (both research and commercial CPUE) may not track population averages well because the emergence of scampi from their burrows seems to vary by size, by sex, by season, and between years. Photographic estimates of absolute abundance or biomass (based on visible scampi) may be similarly affected. Conversely, photographic estimates of relative abundance based on burrows should not be affected by emergence, and these are more faithfully reproduced by the model. Some length frequency distributions, especially those collected by scientific observers on commercial trawlers, are poorly reproduced by the model, but this might be a result of the vagaries of commercial fishing and the relatively small number and poor geographical spread of samples (compared with research samples which are generally randomised). The model is sensitive to some priors, and to modelling assumptions about the shape of the stock-recruit relationship, the variability of recruitment success, the choice of error structure for length frequency distributions (the dominant contributors to the likelihood function), and to the omission of observed selectivity at length data.

The main developments since the version of this model discussed by the SFAWG are a more formal restriction of the input data to the “core” area of the QMA 1 scampi fishery (Mercury Islands to White Island, 300–500 m depth), the application of multinomial error structure to length frequency distributions, the internal estimation of some process error components, the inclusion of, and fitting to, more data on codend selectivity at length (using asymmetrical Richards curves), and the inclusion of more length frequency distributions derived from photographic surveys. The first iteration of the model suggested an initial spawning stock biomass ( $B_0$ ) of less than 2000 t in QMA 1 and a biomass of around 40% of  $B_0$  in 2003. This second iteration is more optimistic, suggesting biomass was about 4700 t in 1985, and the current (2003) biomass is about 3700 t (79% of  $B_0$ ). The estimated posterior distribution of  $B_0$  is very broad, however, and skewed to the right. Likelihood profiling suggests that a wide range of biomass estimates are similarly plausible (have similar likelihoods), but the model is extremely limited in its ability to explore values of  $M$  much different from the MPD fit of  $0.21 \text{ yr}^{-1}$ . Under the base model structure and assumptions, a  $B_0$  of less than 2000 t is unlikely.

## 1. INTRODUCTION

This report outlines a Bayesian, length-based, two-sex population model for Bay of Plenty (QMA 1) scampi up to the end of the 2002–03 fishing year. This is the first attempt at developing a length-based population model for any scampi stock and has been implemented using the general-purpose stock assessment program CASAL v2.06 (September 2004) (Bull et al. 2004). We describe the available data and how they were used, the parameterisation of the model, and model fits and sensitivity. The model has many inadequacies, but we nevertheless provide a preliminary estimate of current stock status. This report fulfils Objective 3 of Project SCI2003/02 “*To carry out stock assessment of scampi in QMA 1, including estimating biomass and sustainable yields*”.

### 1.1 Description of the fishery

The New Zealand trawl fishery for scampi developed first in QMA 1 in 1987–88. It has been conducted mainly by 20–40 m vessels using light, bottom trawl rigs consisting of two or three nets of very low headline height. Currently, the main fisheries are in waters 300–550 m deep in QMA 1 (Bay of Plenty), QMA 2 (Hawke Bay and Wairarapa coast), QMA 3 (Mernoo Bank) QMA 4 (western Chatham Rise and Chatham Islands), and QMA 6 (Sub-Antarctic) (Figure 1, Table 1). Some fishing has been reported on the Challenger Plateau outside the EEZ.

Scampi was introduced to the QMS on 1 October 2004. Until the introduction, access to the fishery had been restricted and, until the 1999–2000 fishing year, there were restrictions on the vessels that could be used in each QMA. Until the 2001–02 fishing year, catches were restrained using a mixture of competitive and individually allocated catch limits. For the 2001–02 to 2003–04 fishing years, all scampi fisheries were managed using competitive catch limits, that for QMA 1 being 120 t.

Following a reasonably consistent decline since 1995–96, unstandardised CPUE in QMA 1 increased by about 40% between 2002 and 2003 (Figure 2). Depending on the index used, catch rates are now on 70% to 84% of those recorded in the index year (1988–89) (Hartill & Cryer 2004). Between 1988–89 and 1997–98, standardised and unstandardised indices of CPUE in QMA 1 were very highly correlated (data from Cryer & Coburn (2000),  $r_s = 0.95$ ,  $p = 0.0003$ ) suggesting that, unless fishing practice changes markedly, the unstandardised index is likely to be a reliable measure of overall catch rate. The depth range fished has remained around 400 m since 1988–89 (although some shallower tows were made 1991–92 to 1994–95, and again since 2000–01) (Figure 3), and the spatial extent of the fishery has remained reasonably consistent in the western Bay of Plenty (Figure 4). Discussions with fishers suggest that trawl mesh sizes have remained similar or identical since about 1993, although some fishers used finer meshes in the early years of the fishery. Thus, fishing practice seems to have been reasonably consistent, at least since 1993.

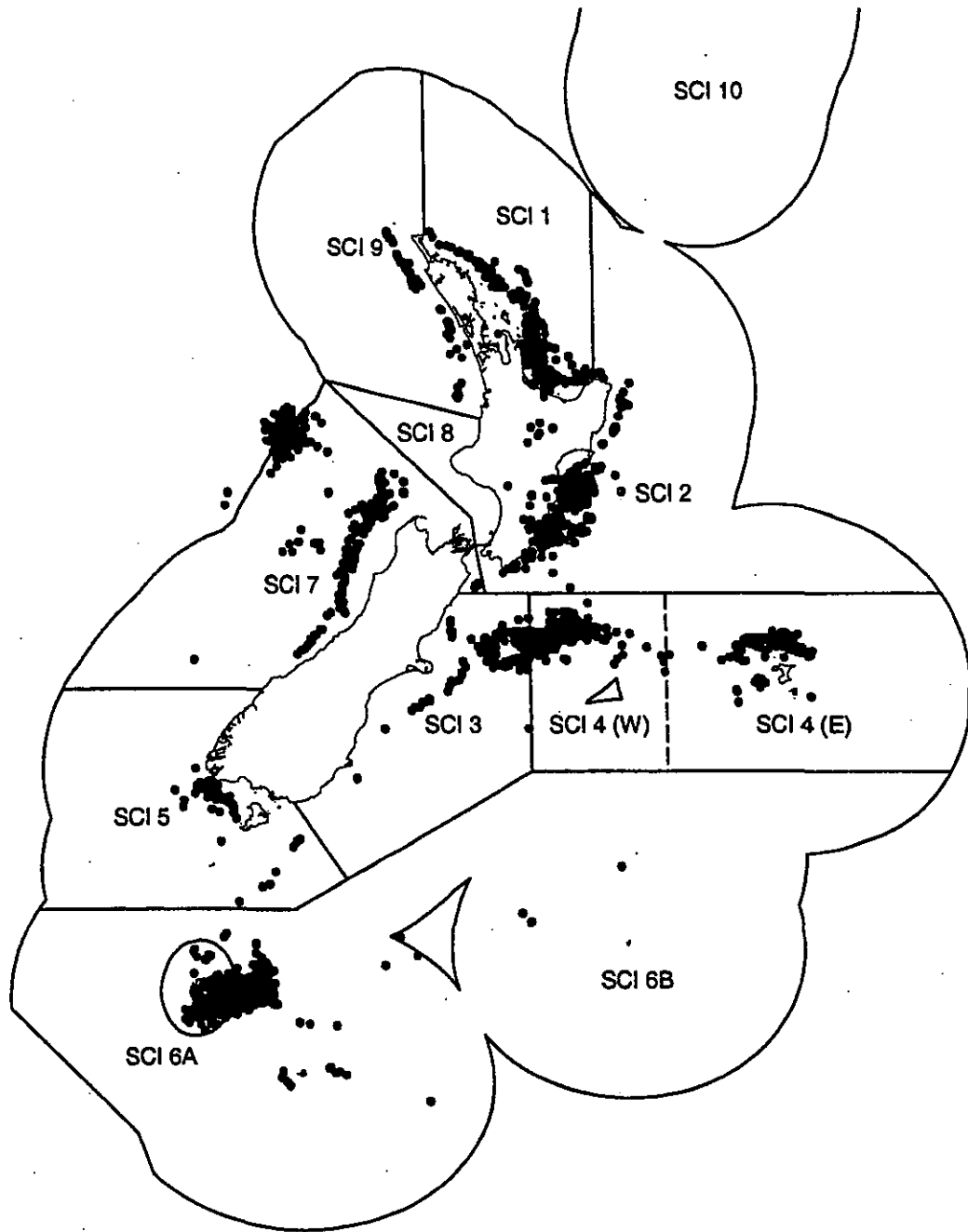


Figure 1 (after Hartill & Cryer 2004): Fishery management areas and the location of the main fishing areas for scampi, *Metanephrops challengeri*, in New Zealand waters during the period relating to this assessment (management areas have since changed). Dots indicate the start positions of trawl tows targeting scampi on Ministry of Fisheries catch/effort databases by December 2003. SCI 6A was a separate management area containing all waters within 50 nautical miles of the Auckland Islands, whereas SCI 4 was informally separated for CPUE analysis into eastern and western portions at longitude 180° (dashed line).

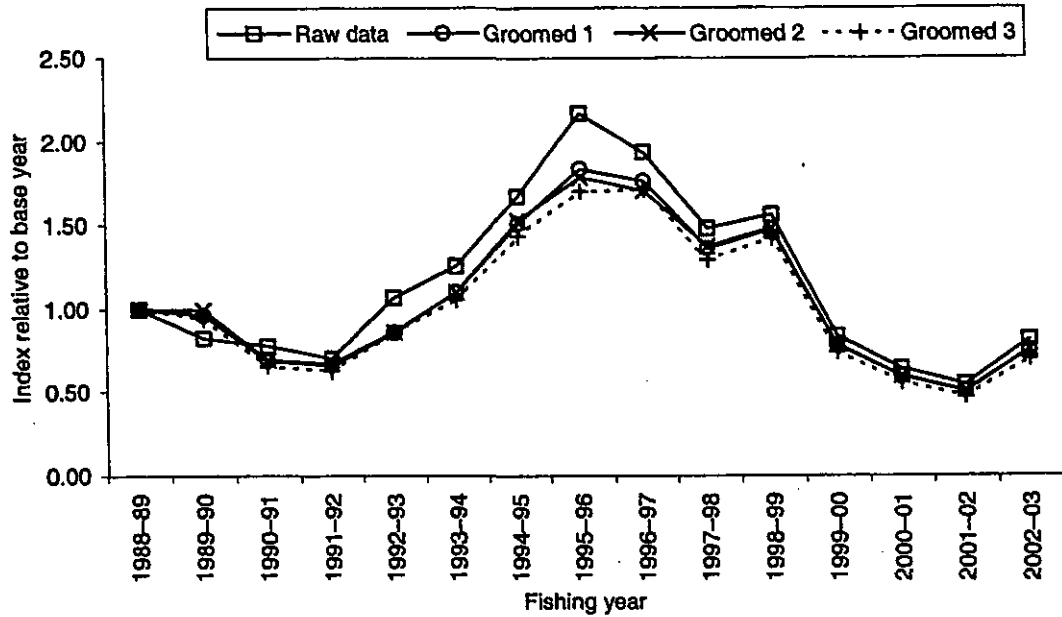


Figure 2 (after Hartill & Cryer 2004): Indices of unstandardised catch rate (total catch divided by total effort, hours) for all vessels fishing in QMA 1. "Raw data", all data with no grooming; "Groomed 1", groomed data with irreconcilable errors included; "Groomed 2", groomed data with irreconcilable errors excluded; "Groomed 3", groomed data with irreconcilable errors and tows with a zero catch of scampi excluded.

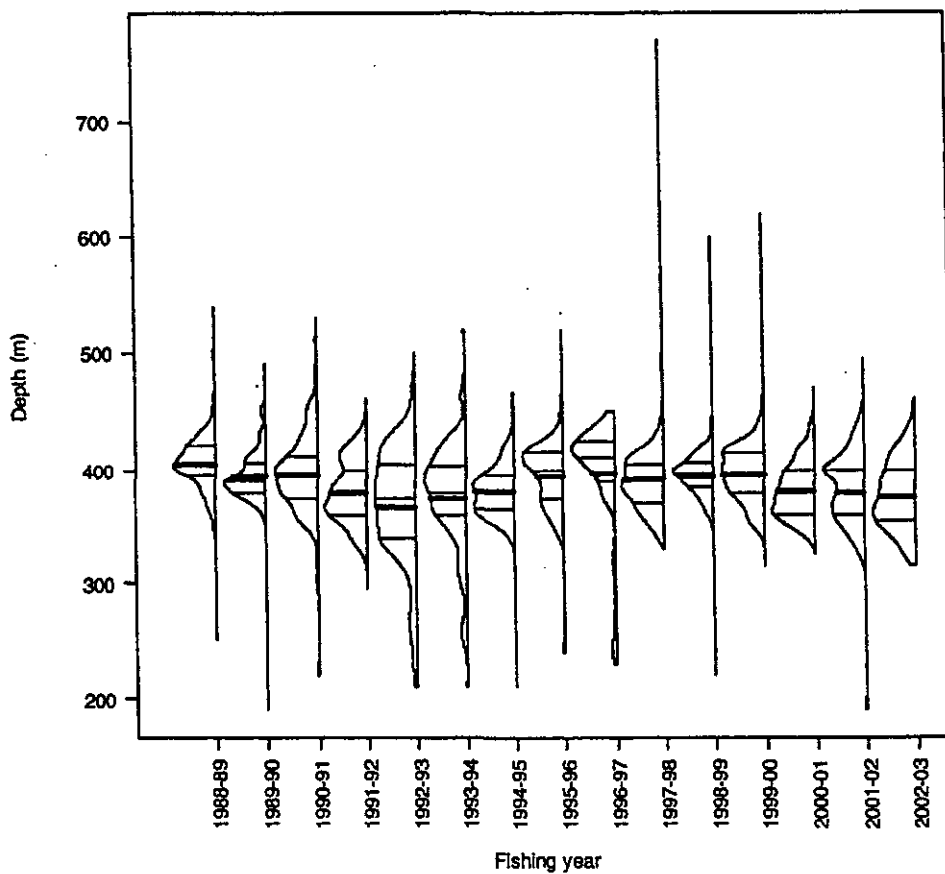
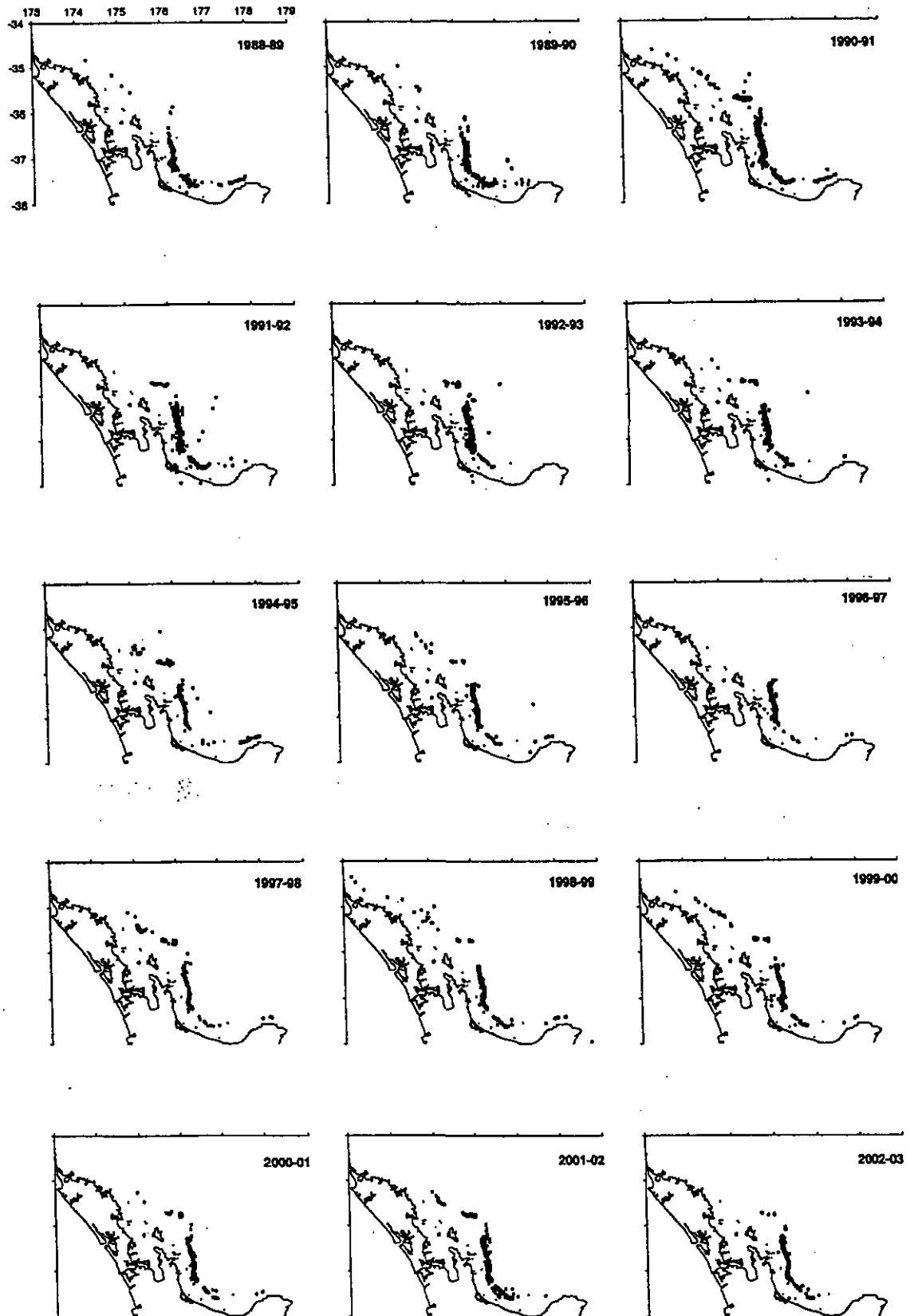


Figure 3 (after Hartill & Cryer 2004): Depth distribution of trawl tows for scampi by fishing year in QMA 1. Bold horizontal line denotes the annual average depth fished, and narrow lines denote the median (where visible) and quartiles.



**Figure 4 (after Hartill & Cryer 2004): Spatial distribution of the QMA 1 scampi trawl fishery since 1988–89. Each dot shows the start position of a tow reported on TCEPR.**



**Table 1 (after Annala et al. 2003): Estimated commercial landings (t) from the 1986–87 to 2000–01 fishing years and catch limits (t) by QMA (from TCEPR, MFish catch effort database, as at December 2002, early years may be incomplete). No limits before 1991–92 fishing year; \* no separate catch limits for QMA 6A and 6B before 1992–93, total catch limit 300 t; (†), catch limits allocated individually until 30 September 2001. Some values may differ from those in (groomed) research data sets.**

|         | QMA 1 |           | QMA 2 |           | QMA 3 |       | QMA 4 |           | QMA 5 |       |
|---------|-------|-----------|-------|-----------|-------|-------|-------|-----------|-------|-------|
|         | Catch | Limit (†) | Catch | Limit (†) | Catch | Limit | Catch | Limit (†) | Catch | Limit |
| 1986–87 | 5     | –         | 0     | –         | 0     | –     | 0     | –         | –     | –     |
| 1987–88 | 15    | –         | 5     | –         | 0     | –     | 0     | –         | 0     | –     |
| 1988–89 | 60    | –         | 17    | –         | 0     | –     | 0     | –         | 0     | –     |
| 1989–90 | 104   | –         | 138   | –         | 0     | –     | 0     | –         | 0     | –     |
| 1990–91 | 179   | –         | 295   | –         | 0     | –     | 32    | –         | 0     | –     |
| 1991–92 | 132   | 120       | 221   | 246       | 1     | 60    | 230   | 250       | 0     | 60    |
| 1992–93 | 114   | 120       | 210   | 246       | 84    | 60    | 223   | 250       | 2     | 60    |
| 1993–94 | 115   | 120       | 244   | 246       | 64    | 60    | 261   | 250       | 1     | 60    |
| 1994–95 | 114   | 120       | 226   | 246       | 66    | 60    | 226   | 250       | 0     | 60    |
| 1995–96 | 117   | 120       | 230   | 246       | 76    | 60    | 230   | 250       | 0     | 60    |
| 1996–97 | 117   | 120       | 213   | 246       | 72    | 60    | 232   | 250       | 2     | 60    |
| 1997–98 | 107   | 120       | 224   | 246       | 60    | 60    | 236   | 250       | 0     | 60    |
| 1998–99 | 110   | 120       | 233   | 246       | 69    | 60    | 251   | 250       | 30    | 60    |
| 1999–00 | 124   | 120       | 193   | 246       | 77    | 60    | 268   | 250       | 9     | 40    |
| 2000–01 | 120   | 120       | 146   | 246       | 79    | 60    | 254   | 250       | 7     | 40    |
| 2001–02 | 124   | 120       | 247   | 246       | 79    | 60    | 255   | 250       | <1    | 40    |

|         | QMA 6A |           | QMA 6B |       | QMA 7 |       | QMA 8 |       | QMA 9 |       |
|---------|--------|-----------|--------|-------|-------|-------|-------|-------|-------|-------|
|         | Catch  | Limit (†) | Catch  | Limit | Catch | Limit | Catch | Limit | Catch | Limit |
| 1986–87 | 0      | –         | 0      | –     | 0     | –     | 0     | –     | 0     | –     |
| 1987–88 | 0      | –         | 0      | –     | 0     | –     | 0     | –     | 0     | –     |
| 1988–89 | 0      | –         | 0      | –     | 0     | –     | 0     | –     | 0     | –     |
| 1989–90 | 0      | –         | 0      | –     | 0     | –     | 0     | –     | 0     | –     |
| 1990–91 | 2      | –         | 0      | –     | 0     | –     | 0     | –     | 0     | –     |
| 1991–92 | 323    | *300      | 2      | *     | 0     | 75    | 0     | 60    | 0     | 60    |
| 1992–93 | 198    | 256       | 81     | 50    | 2     | 75    | 0     | 60    | 2     | 60    |
| 1993–94 | 242    | 256       | 61     | 50    | 0     | 75    | 0     | 60    | 1     | 60    |
| 1994–95 | 225    | 256       | 14     | 50    | 2     | 75    | 0     | 60    | 0     | 60    |
| 1995–96 | 220    | 256       | 50     | 50    | 1     | 75    | 0     | 60    | 0     | 60    |
| 1996–97 | 230    | 256       | 45     | 50    | 0     | 75    | 0     | 60    | 0     | 60    |
| 1997–98 | 244    | 256       | 35     | 50    | 0     | 75    | 0     | 60    | 0     | 60    |
| 1998–99 | 273    | 256       | 53     | 50    | 1     | 75    | 0     | 60    | <1    | 60    |
| 1999–00 | 255    | 256       | 73     | 50    | 1     | 75    | 0     | 5     | 0     | 35    |
| 2000–01 | 227    | 256       | 37     | 50    | <1    | 75    | 0     | 5     | 0     | 35    |
| 2001–02 | 253    | 256       | 19     | 50    | <1    | 75    | 0     | 5     | 0     | 35    |

## 1.2 General biological knowledge

Scampi, *Metanephrops challengeri*, are widely distributed around the New Zealand coast, principally in depths between 200 and 600 m on the continental slope. Like other species of *Metanephrops* and *Nephrops*, *M. challengeri* builds a burrow in the sediment and may spend a considerable proportion of time within this burrow. From trawl catch rates, it appears that there are daily, seasonal, and, perhaps, longer-term cycles of emergence from burrows on to the sediment surface.

Scampi moult several times per year in early life and probably about once a year after sexual maturity (at least in females). Data from trawl surveys in QMA 1 and 2 suggest that females as small as 30 mm OCL can be sexually mature in these areas. The peak of moulting and spawning activity seems to occur in spring or early summer (Cryer & Oliver 2001). Larval development is probably very short, and may be less than 3 days in the wild (Wear 1976). The abbreviated larval phase may, in part,

explain the low fecundity of *M. challengerii* compared with *N. norvegicus* (some tens to a few hundreds of eggs, compared with a few thousands).

Inferences about the growth rate of scampi have been drawn from tagging studies, aquarium experiments, and length frequency distributions (Table 2). The maximum age of New Zealand scampi is not known, although analysis of the tag return data and aquarium trials suggest that this species may be quite long lived (Cryer & Stotter 1999, Cryer & Oliver 2001). *Metanephrops* spp. in Australian waters may grow rather slowly and take up to 6 years to recruit to the commercial fishery, consistent with early estimates of growth in *M. challengerii*. *N. norvegicus* populations in some northern European populations grow to about 30 mm carapace length after 3–4 years (Figure 5) and achieve a maximum age of 15–20 years, broadly consistent with the estimates of natural mortality, *M*, for *M. challengerii*.

Table 2 (after Annala et al. 2003): Estimates of biological parameters.

| Population   | Estimate                   | Source                         |                           |
|--|----------------------------|--------------------------------|---------------------------|
| <b>1. Weight = a(orbital carapace length)<sup>b</sup> (weight in g, OCL in mm)</b> |                            |                                |                           |
| All males: QMA 1   | a = 0.000373               | b = 3.145                      | Cryer & Stotter (1997)    |
| Ovigerous females: QMA 1   | a = 0.003821               | b = 2.533                      | Cryer & Stotter (1997)    |
| Other females: QMA 1   | a = 0.000443               | b = 3.092                      | Cryer & Stotter (1997)    |
| All females: QMA 1   | a = 0.000461               | b = 3.083                      | Cryer & Stotter (1997)    |
| <b>2. von Bertalanffy growth parameters</b>  |                            |                                |                           |
|  | <b>K (yr<sup>-1</sup>)</b> | <b>L<sub>∞</sub> (OCL, mm)</b> | <b>t<sub>0</sub> (yr)</b> |
| Females: QMA 1 (tag)   | 0.11–0.14                  | 48.0–49.0                      | 0.0                       |
| Females: QMA 2 (aquarium)  | 0.31                       | 48.8                           | 0.0                       |
| Males: QMA 2 (aquarium)  | 0.32                       | 51.2                           | 0.0                       |
| <b>3. Natural mortality (M)</b>  |                            |                                |                           |
| Females: QMA 1   | M = 0.20–0.25              |                                | Cryer & Stotter (1999)    |

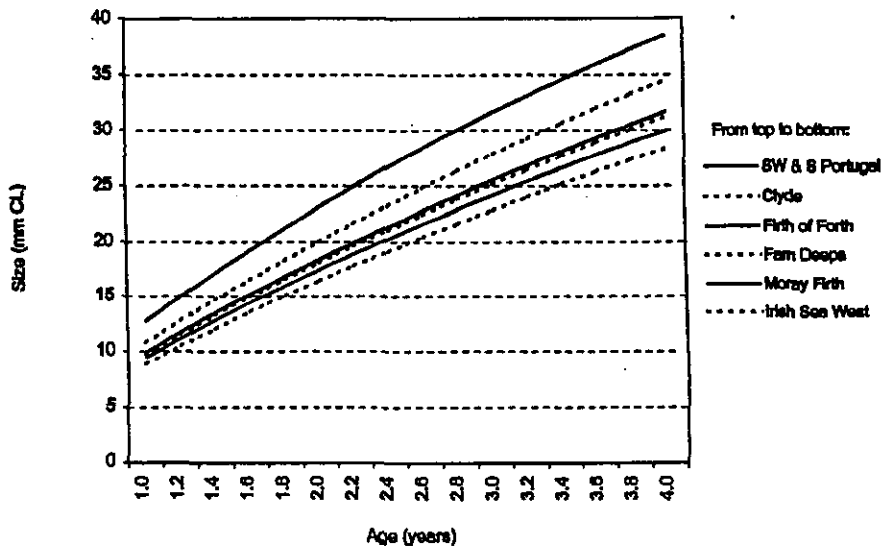


Figure 5 (after ICES 2000): Early growth curves for six European populations of *Nephrops norvegicus*. No reliable information is available on the growth of juveniles of any species of *Metanephrops*.

## 2. MODEL STRUCTURE, INPUTS, AND ESTIMATION

### 2.1 General structure of the model

The population model partitions QMA 1 scampi into a two-sex population, with 66 length bins having lower limits of 1–66 mm orbital carapace length (OCL), the last being a “plus group”. The “stock” is assumed to reside in a single, homogeneous area between the Mercury Islands and White Island, 300–500 m depth. The partition accounts numbers of males and females by length class within an annual cycle, where movements between length classes are determined by sex-specific, length-based growth parameters. Individuals enter the partition by recruitment and are removed by natural mortality and fishing mortality. The model’s annual cycle is based on the fishing year and is divided into two time-steps (Table 3). Note that model references to “year” within this report refer to the fishing year, and are labelled as the most recent calendar year, i.e., the fishing year 1998–99 is referred to as “1999” throughout.

**Table 3: Annual cycle of the population model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur together within a time step occur after all other processes, with 50% of the natural mortality for that time step occurring before and 50% after the fishing mortality.**

| Step | Period  | Process           | Proportion in time step |
|------|---------|-------------------|-------------------------|
| 1    | Oct–Dec | Recruitment       | 1.0                     |
|      |         | Maturation        | 1.0                     |
|      |         | Natural mortality | 0.25                    |
|      |         | Fishing mortality | From TCEPR              |
| 2    | Jan–Sep | Natural mortality | 0.75                    |
|      |         | Growth            | 1.0                     |
|      |         | Fishing mortality | From TCEPR              |

Catches occur in both time steps during 1985–86 to 2002–03 (see Table 1 for the whole QMA, Table 4 for the modelled area) and we divided the catch among the two according to the proportion of estimated catches recorded on Trawl catch, Effort, and Processing Returns (TCEPR). Recreational catch, customary catch, and illegal catch are ignored. The maximum exploitation rate (i.e., the ratio of the maximum catch to biomass in any year) is not known, but we constrained it to no more than 0.9 in a time-step (i.e., we assume that no more than 90% of the stock can be taken in a time step). Individuals are assumed to recruit to the model at age 0, with the mean expectation of recruitment success predicted by a Beverton & Holt stock-recruitment relationship. Length at recruitment is defined by a normal distribution with mean of 1 mm OCL with a c.v. of 0.4. Relative year class strengths are encouraged to average 1.0. Growth is assumed known (from tag and aquarium data), but natural mortality is estimated.

The model uses three asymmetrical (Richards) length-based selectivity ogives for commercial fishing, research trawl surveys, and photographic surveys (all assumed constant over both sexes, all years, and all time steps of the fishery). A length-based symmetrical (logistic) maturity ogive is used, and assumed to be identical for males and females (though we have data only for the latter). The logistic curve is parameterised for each length class  $x$  as:

$$f(x) = \frac{1}{\left[ 1 + 19^{(a_{50}-x)/a_{1095}} \right]}$$

where  $x$  is the centre of the length class and estimatable parameters are  $a_{50}$  and  $a_{1095}$ . Richards curves are more complex and involve an asymmetry term as well as the terms describing central tendency and steepness:

$$f(x) = \left( \frac{1}{1 + 19^{(\alpha-x)/\beta}} \right)^{\frac{1}{\delta}}$$

$$\text{where } \beta = \frac{a_{1095} \log(19)}{\log(2^\delta - 1) - \log\left(\left(\frac{20}{19}\right)^\delta - 1\right)}$$

$$\text{and } \alpha = a_{50} + \frac{\beta \log(2^\delta - 1)}{\log(19)}$$

where  $x$  is similarly the centre of the length class and estimatable parameters within CASAL are  $a_{50}$ ,  $a_{1095}$ , and  $\delta$ . Selectivity and maturity ogives were fitted within the model.

## 2.2 Biological inputs, priors, and assumptions

### 2.2.1 Recruitment

Few data are available on recruitment. Relative year class strengths area were assumed to average 1.0 over all years of the model. Lognormal priors on relative year class strengths were assumed, with mean 1.0 and c.v. 0.2. The relationship between stock size and recruitment for scampi is unknown. However, New Zealand scampi have very low fecundity (in the order of tens to hundreds of eggs carried by each female), so very successful recruitment is probably not plausible at low abundance. Scampi enter the model partition at age 0+, before growth as 1 year olds. The distribution of their sizes was assumed to be normally distributed with mean 1 mm OCL and c.v. of 0.4.

### 2.2.2 Growth (tagging and aquarium experiments)

Cryer & Stotter (1997, 1999) and Cryer & Oliver (2001) estimated growth from wild-tagged scampi in QMA 1 and aquarium-reared scampi from QMA 2, respectively (Figures 6 & 7). Recoveries and measurements of captive animals were made at a variety of intervals, so growth models were based on a modified length increment von Bertalanffy growth model, estimated using maximum likelihood, mixed effects models (after Francis 1988). Cryer & Oliver (2001) estimated  $g_{30}$  (expected annual increments for scampi of 30 mm OCL) at 5.01 mm for males and 5.26 mm for females, and estimated  $g_{50}$  at 1.05 mm for males and -0.82 mm for females. Because negative growth is disallowed in CASAL, we interpolated equivalent values of  $g_{20}$  (6.99 mm for males and 8.30 mm for females) and  $g_{40}$  (3.03 mm for males and 2.22 mm for females). Growth variability ( $s_{min}$ ) was specified as 1.5 mm after Cryer & Oliver (2001). Thus, growth of an animal of size class  $i$  is normally distributed with a mean of:

$$\mu = g_\alpha + \frac{(g_\beta - g_\alpha)(l_{ci} - l_\alpha)}{(l_\beta - l_\alpha)}$$

and standard deviation of:

$$\sigma = \max(c\mu, s_{min})$$

where  $l_i$  is the lower bound of the size class and  $l_{ci} = (l_i + l_{i+1})/2$ . The growth estimates of Cryer & Stotter (1999) and Cryer & Oliver (2001) and the derived estimates used in these models have several limitations. They were generated using a combination of data from tagged animals (in QMA 1) and aquarium-reared animals (from QMA 2 but maintained at 12 °C). The tag data may suffer from both catching (trawling) and tagging artefacts (which, if present, would both generally lead to some retardation of average growth), and very few small or medium-sized males were recaptured. Conversely, tagged scampi were released in about 400 m depth and would have been exposed to “normal” temperatures of about 10 °C (Figure 8). Aquarium-reared scampi were collected from QMA 2 (again, by trawl), where average growth may be different than in QMA 1. A wider range of size classes of both males and females is included in this data set, although relatively few large males. The holding temperature of 12 °C may have resulted in accelerated growth, but little is known of the artefacts of holding scampi for long periods or of the artificial diet. Thus, both data sets have their limitations and, in addition, there is no consensus on the most appropriate means of combining the two.

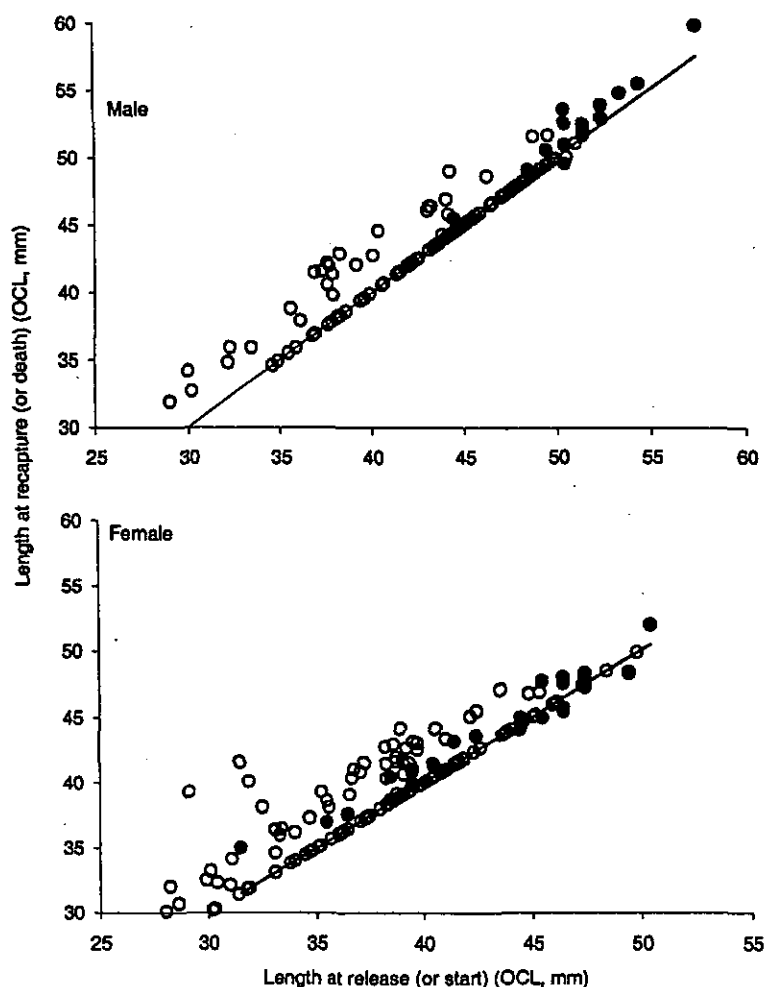


Figure 6 (after Cryer & Oliver 2001): Relationship between size at release and recapture for tagged males (top) and females (bottom) (closed circles, data from Cryer & Stotter 1999) overlaid with comparable data from aquarium trials (open circles) where the increment was measurable. The line indicates no growth.

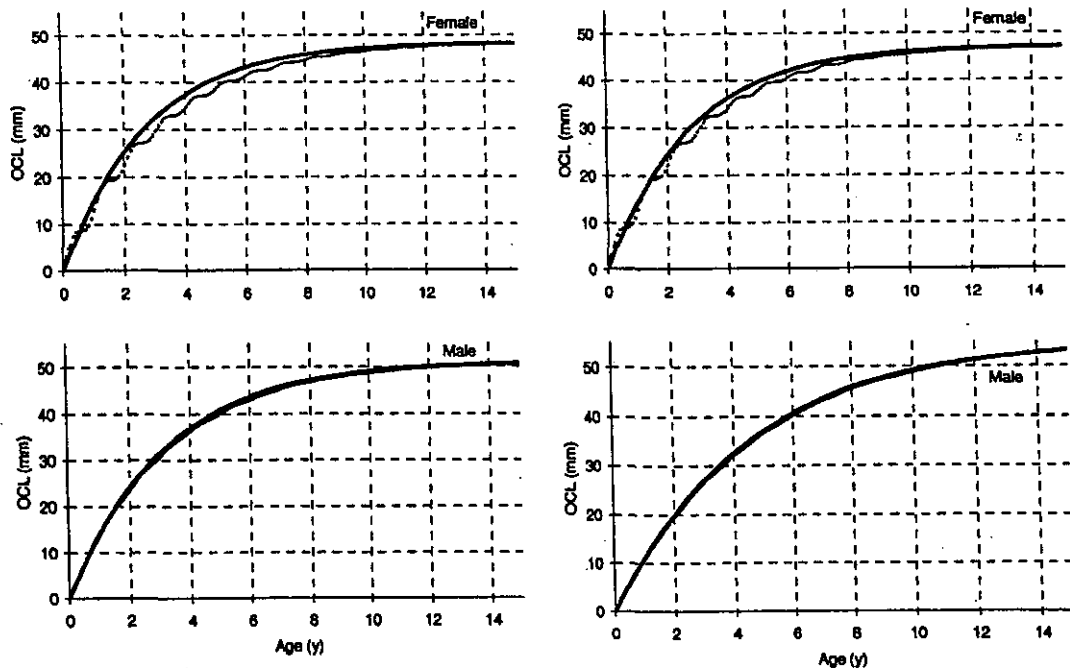


Figure 7 (after Cryer & Oliver 2001): Age-based von Bertalanffy growth curves calculated from GROTAG estimates of growth-at-length for female (top) and male (bottom) scampi assuming  $t_0 = 0$  and a linear relationship between length and mean annual increment. Left panels show curves using only captive animals, right panels using captive and wild-released animals.

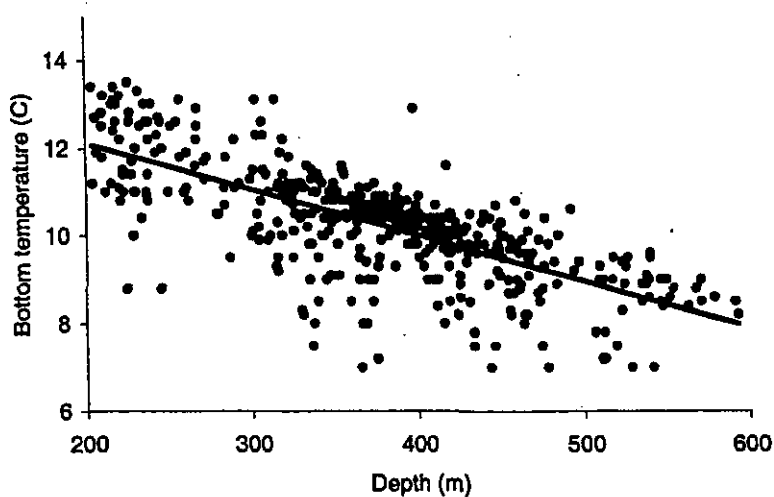


Figure 8 (after Cryer & Oliver 2001): Bottom temperatures recorded using a calibrated headline monitor on 475 trawl shots made between 200 and 600 m depth in the Bay of Plenty, Hawke Bay, or Wairarapa coast, 1992–2000. The line is an ordinary least squares regression.

### 2.2.3 Maturity

The proportion of females mature at each 1 mm size class has been recorded during all research surveys since 1993. Cryer & Oliver (2001) pooled the available data for females from QMAs 1 and 2, assuming internal gonad stages 2–5 to be mature, and stage 1 to be immature (Figure 9). No data are available for the maturity of male scampi, so their maturity ogive was assumed identical to that of females. Maturity is not considered to be a part of the model partition, but proportions mature were fitted within the model based on a logistic ogive with a binomial likelihood (Bull et al. 2004).

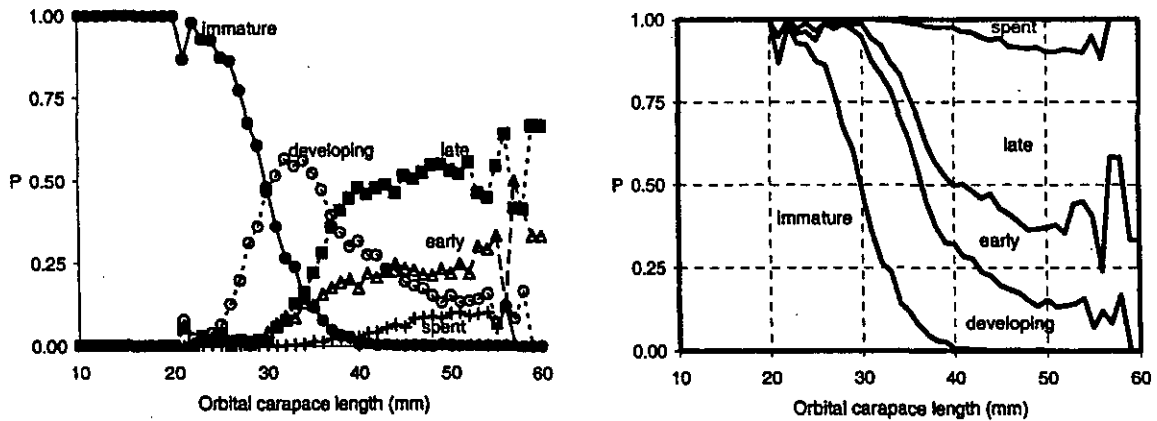


Figure 9 (after Cryer & Oliver 2001): Proportions of female scampi having various developmental stages of internal ovaries. Left panel shows proportions for each stage separately, right panel shows combined proportions. Aggregated data from research voyages in QMAs 1 & 2.

## 2.2.4 Natural mortality

The instantaneous rate of natural mortality,  $M$ , has not been estimated directly for scampi, but Cryer & Stotter (1999) used a correlative method (after Pauly 1980, Charnov et al. 1993) based on their estimate of the  $K$  parameter from a von Bertalanffy growth curve. Based on this rough-and-ready estimate (Figure 10), we placed a log-normally distributed prior on  $M$  of 0.2 and tested c.v.s of 0.2, 0.4, and 0.8 with little effect on the behaviour of the model.

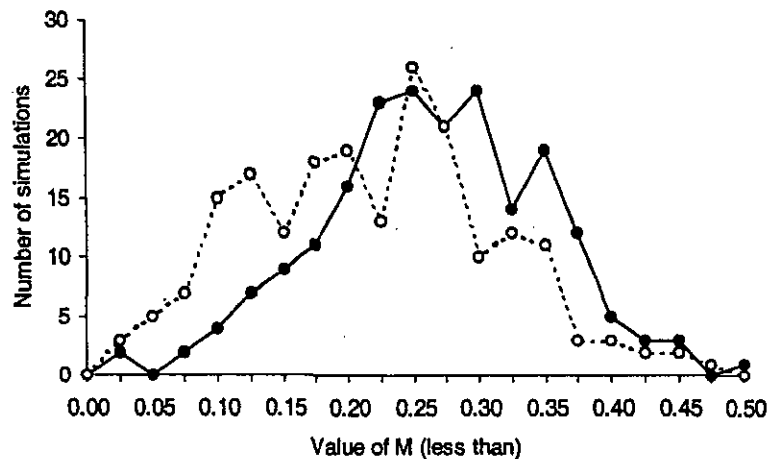


Figure 10 (after Cryer & Stotter 1999): Frequency distributions, from 200 bootstrap replicates, of the estimated rate of natural mortality,  $M$ , based on Charnov et al.'s (1993) regression of  $M$  on the von Bertalanffy  $K$ . Solid lines with solid circles represent the analysis using Ricker's (1975) method, while dashed lines and open circles indicate the analysis using the method of Francis (1988).

## 2.3 Catch data

### 2.3.1 Commercial catch

Scampi trawlers have recorded tow-by-tow information on Trawl Catch, Effort, and Processing Returns (TCEPR) since 1988–89. Catch by year was taken from Annala et al. (2003), and apportioned between the early and late seasons (October to December and January to September) in proportion to the sum of estimated catches on TCEPRs for those months. For the modelled area, commercial tows were included in the catch if they had a reported fishing depth between 300 and 500 m (both inclusive) and they finished within the model area (defined as research strata 302, 303, 402, and 403 used in trawl and photographic surveys, Figure 11) or if their estimated midpoint was within the model area. Overall, about 35% of the QMA's catch was judged to have been taken outside the core area, mostly to the north, but this was not consistent between years (range 0–65%, Table 3).

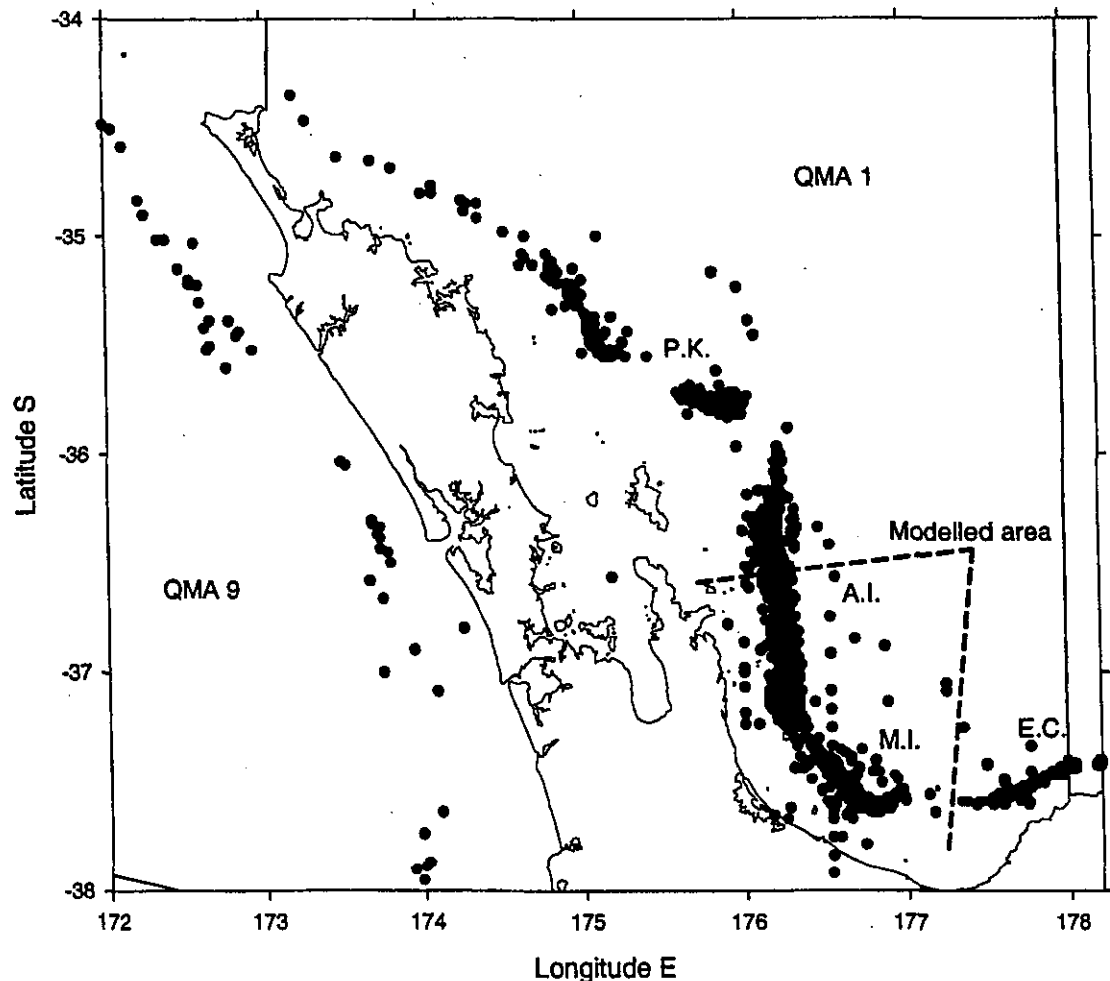


Figure 11: Locations of commercial tows for scampi in QMA 1 reported on TCEPR forms up to the end of the 2002–03 fishing year. General fishing areas nominated in the text are labelled P.K (Poor Knights), A.I. (Aldermen Islands), M.I. (Mayor Island), and E.C. (East Cape), and the area included in the model is delineated by the dashed lines. Many reported trawl tows are obscured, especially within the modelled area, because subsequent tows have the same reported start location.



**Table 3: Estimated landed catch (t) from the whole of QMA 1 and within the modelled area in each year and time step.**

| Year  | QMA 1 catch |         |         | Modelled area catch |        |         | Proportion |        |         |
|-------|-------------|---------|---------|---------------------|--------|---------|------------|--------|---------|
|       | Step 1      | Step 2  | Total   | Step 1              | Step 2 | Total   | Step 1     | Step 2 | Overall |
| 1986  | 0.0         | 0.0     | 0.0     | 0.0                 | 0.0    | 0.0     | -          | -      | -       |
| 1987  | 1.3         | 3.8     | 5.1     | 1.3                 | 3.8    | 5.1     | 1.00       | 1.00   | 1.00    |
| 1988  | 3.8         | 11.3    | 15.1    | 3.8                 | 11.3   | 15.1    | 1.00       | 1.00   | 1.00    |
| 1989  | 15.0        | 45.0    | 60.0    | 0.0                 | 58.0   | 58.0    | 0.00       | 1.29   | 0.97    |
| 1990  | 29.8        | 74.2    | 104.0   | 29.7                | 68.9   | 98.6    | 1.00       | 0.93   | 0.95    |
| 1991  | 26.4        | 152.6   | 179.0   | 24.8                | 85.2   | 110.0   | 0.94       | 0.56   | 0.61    |
| 1992  | 66.3        | 65.7    | 132.0   | 55.3                | 44.6   | 99.9    | 0.83       | 0.68   | 0.76    |
| 1993  | 29.2        | 84.8    | 114.0   | 10.2                | 67.0   | 77.2    | 0.35       | 0.79   | 0.68    |
| 1994  | 58.1        | 56.9    | 115.0   | 38.1                | 36.0   | 74.1    | 0.66       | 0.63   | 0.64    |
| 1995  | 40.9        | 73.1    | 114.0   | 13.0                | 26.9   | 39.9    | 0.32       | 0.37   | 0.35    |
| 1996  | 53.1        | 63.9    | 117.0   | 22.2                | 40.3   | 62.5    | 0.42       | 0.63   | 0.53    |
| 1997  | 41.5        | 75.5    | 117.0   | 28.4                | 40.6   | 69.0    | 0.68       | 0.54   | 0.59    |
| 1998  | 72.3        | 34.7    | 107.0   | 35.4                | 24.4   | 59.8    | 0.49       | 0.70   | 0.56    |
| 1999  | 44.3        | 65.7    | 110.0   | 37.0                | 51.7   | 88.7    | 0.84       | 0.79   | 0.81    |
| 2000  | 20.0        | 104.0   | 124.0   | 7.3                 | 64.8   | 72.1    | 0.37       | 0.62   | 0.58    |
| 2001  | 45.7        | 74.3    | 120.0   | 25.4                | 51.2   | 76.6    | 0.56       | 0.69   | 0.64    |
| 2002  | 119.2       | 4.8     | 124.0   | 63.4                | 4.3    | 67.7    | 0.53       | 0.90   | 0.55    |
| 2003  | 95.8        | 20.0    | 115.8   | 81.4                | 0.0    | 81.4    | 0.85       | 0.00   | 0.70    |
| Total | 762.7       | 1 010.3 | 1 773.0 | 476.7               | 679.0  | 1 155.7 | 0.63       | 0.67   | 0.65    |

### 2.3.2 Recreational catch

There is no known recreational catch of scampi and any such catch is ignored in the model.

### 2.3.3 Customary catch

There is no known customary catch of scampi and any such catch is ignored in the model.

### 2.3.4 Illegal catch

We have no information on illegal catches of scampi and they are ignored in the model.

### 2.3.5 Incidental mortality

We have no information on the incidental mortality caused by the trawl method or on discard mortality caused by the exclusion of any damaged and discarded animals from reported landings. Both are assumed to be negligible (based on our experience of the fishery as well as the lack of quantitative information) and are ignored in the model.

### 2.3.6 Length frequency of the commercial catch

Length frequency samples from the commercial catch have been taken by scientific observers since 1992 (e.g., see Hartill & Cryer 2000 for an extensive review). Estimates of the length-frequency (with associated c.v.s) of the commercial catch were derived using the NIWA catch-at-age software (Bull & Dunn 2002), using 1 mm (OCL) length classes by sex, weighting the proportions at length in each of four general areas (Poor Knights Islands, Aldermen Islands, Mayor Island, and East Cape) by the amount of catch estimated to have been taken from these areas using the estimated catches reported on TCEPR. Length frequency distributions were calculated separately for the sexes and for early and late steps in the model (Figure 12). When restricting catch length frequency distributions to the modelled area (Table 4), the same criteria were used as for estimating the core catch. Only Aldermen Islands and Mayor Island areas are within the modelled area, slightly simplifying the weighting procedures.

**Table 4: Actual number of scampi measured by observers in each time step of year between 1990–91 and 2001–02 in QMA 1 and in the modeled (“Core”) area of the fishery, and the estimated effective sample size for assumed multinomial error structure. –, no observer length frequency measurements made; 1991, 1990–91 fishing year.**

| Model<br>Year | Step 1 (Oct.–Dec.) |       |           | Step 2 (Jan.–Sept.) |        |           |
|---------------|--------------------|-------|-----------|---------------------|--------|-----------|
|               | QMA 1              | Core  | Effective | QMA 1               | Core   | Effective |
| 1991          | –                  | –     | –         | 10 245              | 7 511  | 2 501     |
| 1992          | 1 717              | 1 717 | 687       | 1 851               | 338    | 187       |
| 1993          | 263                | 155   | 93        | –                   | –      | –         |
| 1994          | –                  | –     | –         | 100                 | –      | –         |
| 1995          | –                  | –     | –         | 2 519               | –      | –         |
| 1996          | 500                | 400   | 268       | 1 754               | –      | –         |
| 1997          | –                  | –     | –         | 1 905               | 1 280  | 622       |
| 1998          | 2 096              | –     | –         | –                   | –      | –         |
| 1999          | –                  | –     | –         | 2 586               | 2 586  | 1 062     |
| 2000          | –                  | –     | –         | 3 891               | 3 004  | 1 309     |
| 2001          | –                  | –     | –         | –                   | –      | –         |
| 2002          | 2 458              | 294   | 191       | –                   | –      | –         |
| Total         | 7 034              | 2 566 | 1 108     | 24 851              | 14 719 | 5 511     |

## 2.4 Resource surveys and other abundance information

### 2.4.1 Photographic estimates of abundance

Photographic surveys of QMA 1 (e.g., Cryer et al. 2003) have been used to estimate the abundance of burrows thought to belong to scampi in 1998, 2000, 2001, 2002, and 2003. We assume this time series to be an index of relative abundance and fitted to these indices within the model using observed c.v.s (assumed log-normally distributed error). For model fits discussed by the Shellfish Fishery Assessment Working Group (SFAWG), these indices were used as relative abundance estimates (Figure 13) with a “non-informative”  $q$  (catchability coefficient) that could not be meaningfully interpreted. Models presented here include abundance indices that have been converted to biomass indices (using estimates of average animal size for each year) and scaled to the whole of the core area. This means that the estimated  $q$  for the photographic index of abundance can be interpreted as the proportion of model biomass explained by the burrows included in the analysis of photographic surveys (assuming 100% occupancy). For the core area model, we placed a log-normally distributed prior on  $q$ -Photo of 1.0 and tested c.v.s of 0.4, and 0.8 (with little obvious effect on the behaviour of the model).

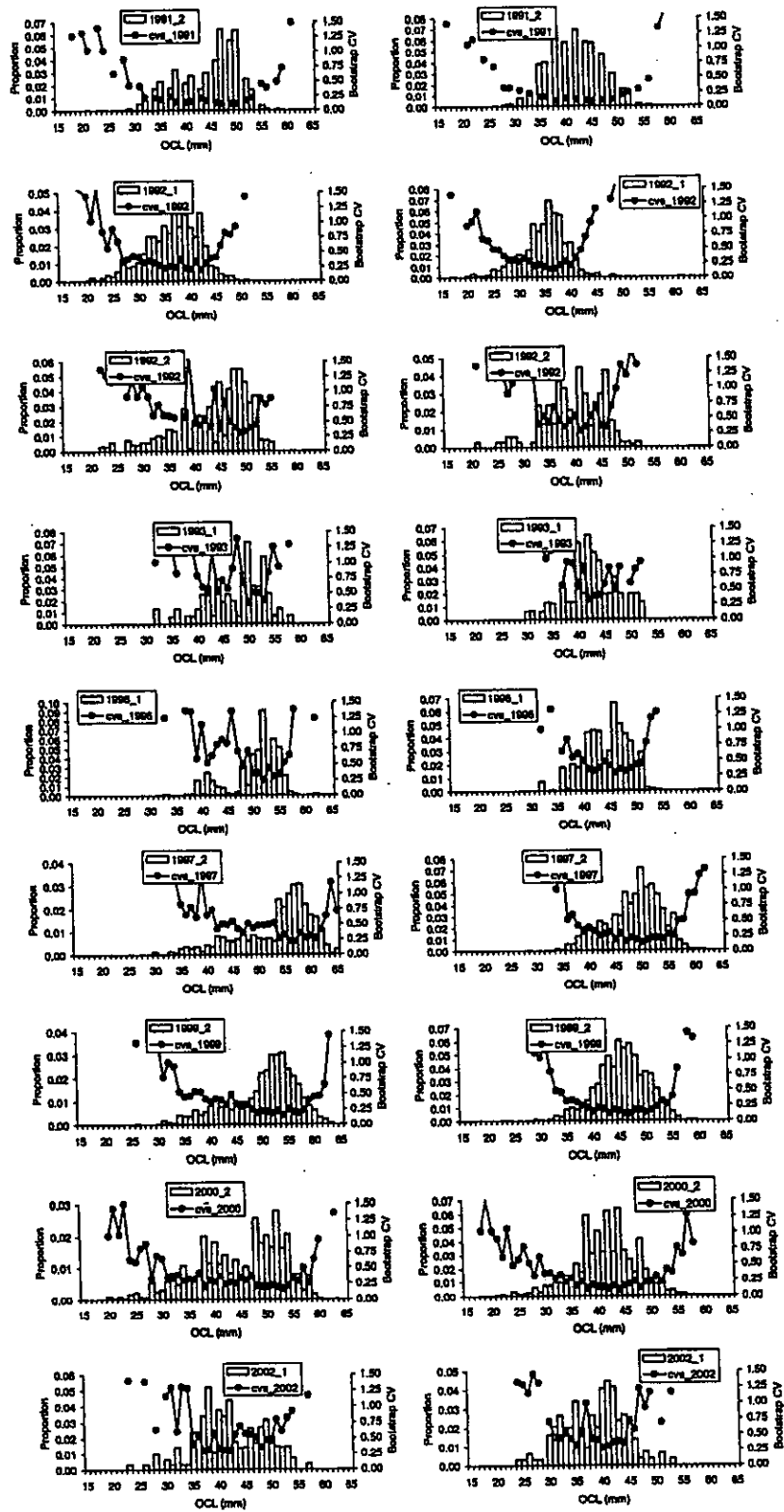


Figure 12: Observer length frequency distributions (histograms) for male (left) and female (right) scampi with bootstrap c.v.s (dots and lines) estimated using NIWA catch-at-age software. "1996\_1" (e.g.) denotes model year and time-step.

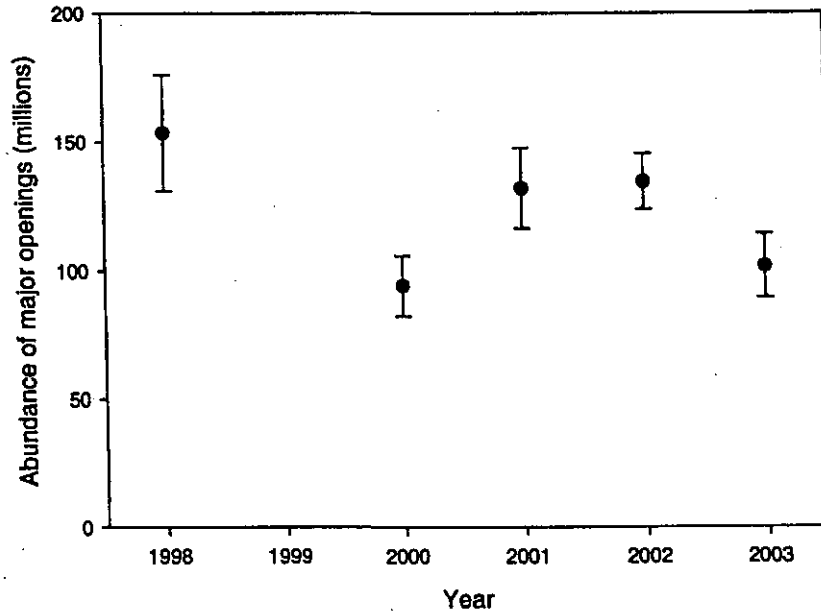


Figure 13 (after Cryer et al. 2003): Estimated abundance ( $\pm$  one standard error) of major burrow openings in strata 302, 303, 402, and 403, 1998 to 2003.

#### 2.4.2 Estimating length frequency distributions from photographs

Length frequency distributions were estimated for the relative photographic abundance series. The widths of a large sample of major burrow openings were measured using *Didger 3.0* image analysis software and converted to orbital carapace lengths using a regression of OCL on major opening width (Figure 14) developed using photographs of scampi clearly associated with burrows. The sample of burrows for measurement was selected on the basis that the image had been identified as having at least two probable burrow openings (to speed the process), and that two or more (of three) readers identified the particular burrow opening as likely to belong to scampi during routine screening to estimate relative biomass (e.g., Cryer et al. 2003). The relationship between OCL and burrow width seems mildly non-linear, so a variety of curvilinear regression models was fitted. The power relationship shown in Figure 14 reproduced roughly the right amount of curvilinearity (by eye) and had the highest  $R^2$  of the models we applied. However, the estimated length frequency distributions were not very sensitive to the regression model applied. To estimate the c.v.s at length for each year, we used a bootstrap procedure, resampling with replacement from the original observations of burrow width, converting each observation to an estimated scampi size (in OCL) using the regression in Figure 14, using an error term sampled from a normal distribution fitted to the regression residuals. Compared with the length frequency distributions from trawl catches, this procedure gave very large c.v.s (Figure 15), but we think this is realistic given the uncertainties involved in generating a length frequency distribution from burrow sizes.

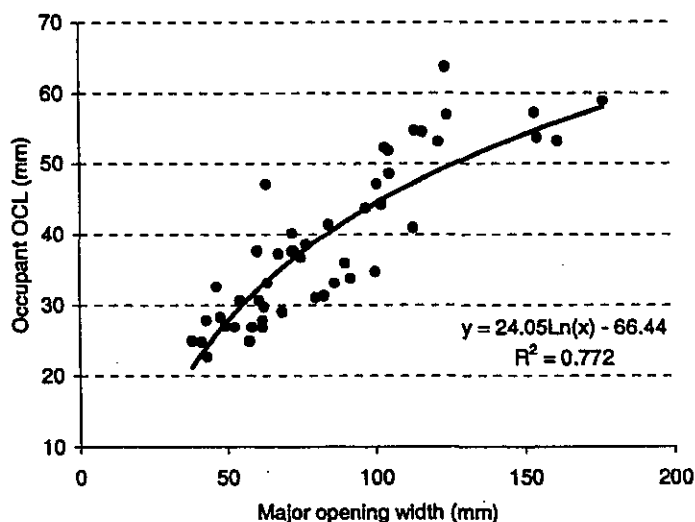


Figure 14: Estimated relationship between the width of a major burrow opening and the size of the occupying scampi (from photographs where animals were clearly associated with burrows). Error in this regression was included in estimated length frequency distributions based on burrow sizes by bootstrapping.

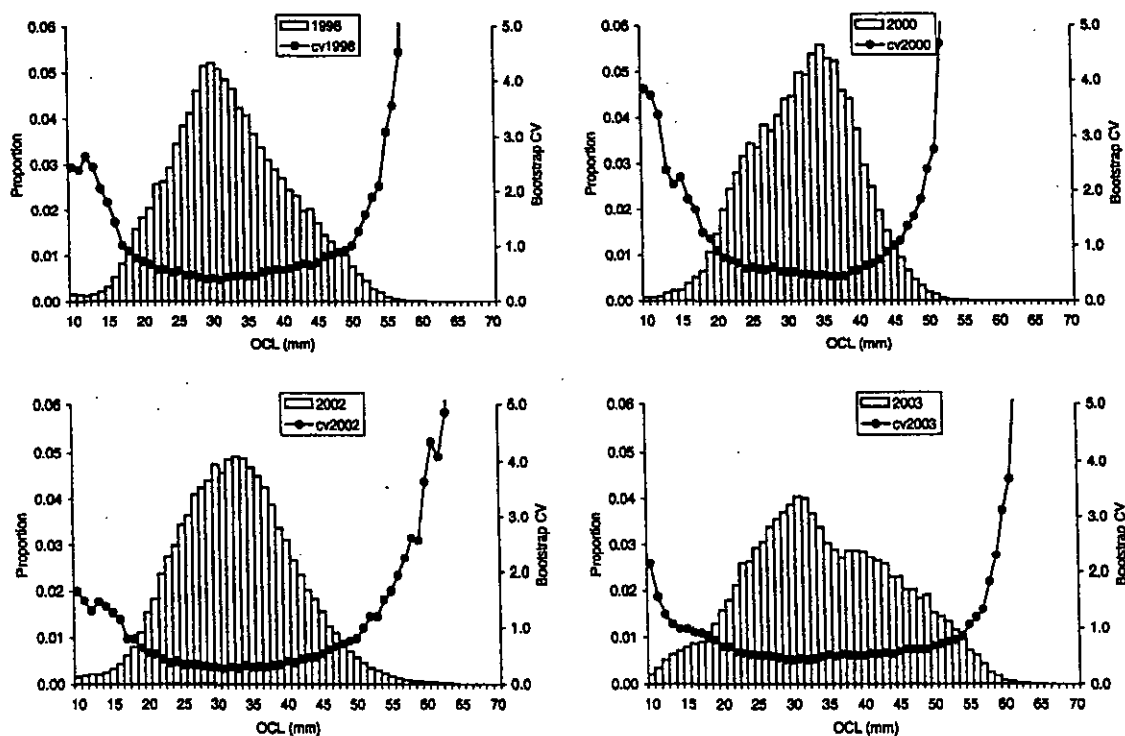


Figure 15: Bootstrapped length frequency distributions (with c.v.s by 1 mm length class) estimated using estimates of major burrow opening widths from photographs and a regression of estimated occupant size on major opening width.

### 2.4.3 Extending photographic information to estimate biomass

Estimating biomass from the photographic estimates of burrow abundance requires assumptions that all burrows (or some specified proportion) are occupied by a scampi, that the length frequency distribution of those scampi can be estimated from the dimensions of the burrows, and that the average weight of a scampi can be estimated from the length frequency distributions. The occupancy assumption remains untested, but the available data do suggest that burrow size increases with animal size (see Figure 14), permitting the estimation of population length frequency distribution from burrow sizes. Using the population length frequency distribution to estimate mean weight requires knowledge (or an assumption) about the population sex ratio, given that the length-weight relationship is steeper for males than for females and that males grow larger than females. For the purpose of this exercise, we assumed that the sex ratio (at length) in scampi caught by research trawling is indicative of that in the population (i.e., their selectivity ogives are the same). Amalgamating all research trawl length frequency distributions from the modelled area (Figure 16) suggests that the sex ratio is about even until the size at maturity, after which females tend to predominate until a size of about 45 mm OCL. Scampi larger than 45 mm OCL are increasingly likely to be males, and those larger than 55 mm OCL are almost certain to be males. This pattern, a predictable consequence of the fact that males grow larger than females, was used to weight predictions of mean weight-at-length for males and females, generating an estimate of population weight-at-length and, in conjunction with the estimated population length frequency distributions and the size of the modelled area, an estimate of standing biomass for each year.

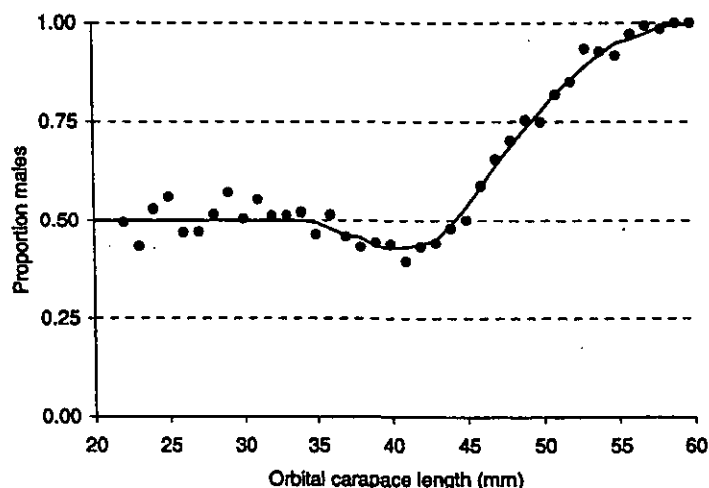


Figure 16: Proportion of males by size class averaged over all research trawl length frequency distributions in the modelled area. The line shows a five-point moving mean (35 mm OCL and above) used to provide a weighting for the estimation of mean individual weight from animal and burrow sizes measured from photographs.

There were more “large” burrows in 2002 and 2003 (suggesting the presence of scampi of 55–60 mm OCL) (see Figure 15), leading to higher estimates of mean weight in those years (25.76 g in 1998, 24.54 g in 2000, 26.26 g in 2002, and 33.01 g in 2003; no data were available for 2001 so we used the mean of estimates for 2001 and 2003). In turn, this leads to higher estimates of biomass relative to the number of burrows. The overall effect is to reduce the level of contrast in the time series and to remove the decline between 2002 and 2003 (Figure 17).

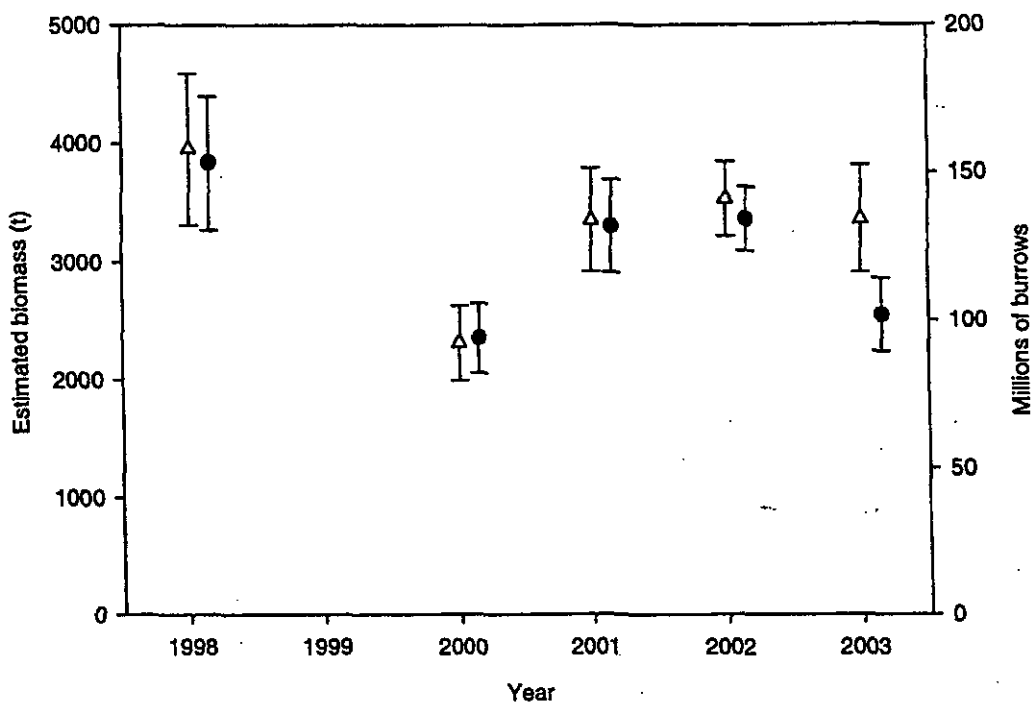


Figure 17: Comparison of abundance indices from photographic surveys. Solid circles show the estimated number of burrows within the modelled area and open triangles show the estimated total biomass (based on the number of burrows and an estimate of average animal weight developed using the size of the burrows in each year and length-weight regressions). Error bars indicate plus or minus one standard error.

#### 2.4.4 Research trawl indices of relative abundance

Stratified random trawl surveys of scampi in QMAs 1 and 2, 200–600 m depth, were conducted in 1993, 1994, and 1995 (see Figure 13). Formal trawl surveys to estimate relative abundance were discontinued because it was inferred from the results (most especially the relative proportions of males and females and the rapidly increasing catch rate) that catchability had varied among surveys. Nevertheless, research trawling has continued in QMA 1 for a variety of other purposes (in support of a tagging programme to estimate growth in 1995 and 1996, to assess selectivity of research and commercial mesh sizes in 1996, and in support of photographic surveys since 1998). Identical gear has been used throughout (30 mm codend and 80 mm wings and belly), or we have selected only those tows where the standard gear was used (on gear selectivity trials). We assume this time series (Figure 18) to be an index of relative abundance (with the caveat that catchability may vary among years and differences in diel timing and depths of tows may have affected the comparability of catch rates among years) and fitted to these indices within the model using observed c.v.s (assumed log-normally distributed). For the modelled area, only tows within strata 302, 303, 402, and 403 were included.

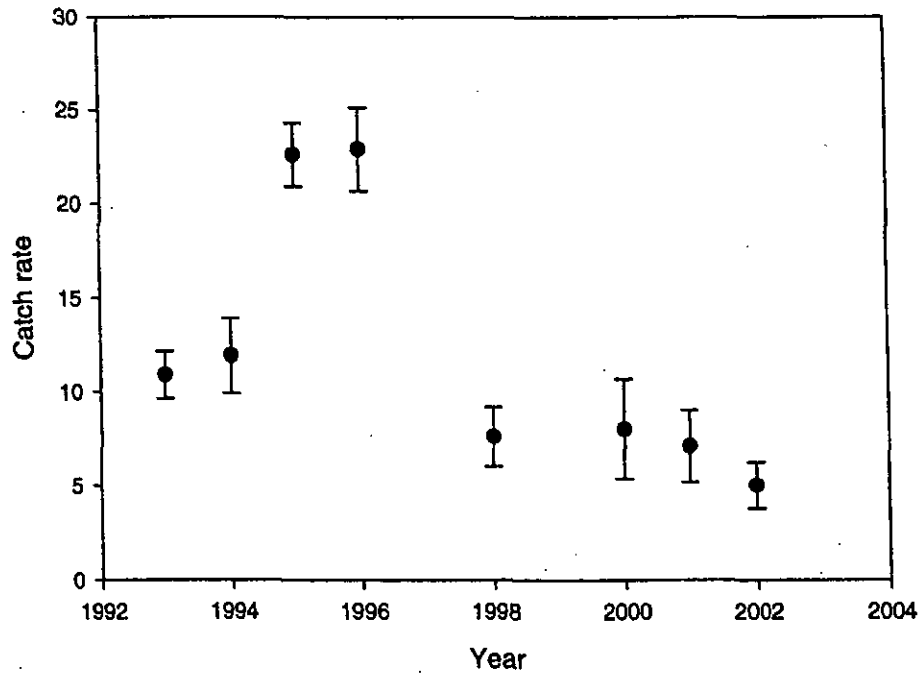


Figure 18: Mean catch rates of research trawling in strata 302, 303, 402, and 403 between 1993 and 2002. The location and diel timing of trawling in 1995, 1996, and 1998 suggest that the former two are likely to be positively biased and the latter negatively biased relative to the rest of the time series.

#### 2.4.5 Length frequency distributions from research trawling

Length frequency samples from research trawling have been taken by scientific staff since 1993 (Table 5). Estimates of the length-frequency (with associated c.v.s) were derived using the NIWA catch-at-age software (Bull & Dunn 2002), using 1 mm (OCL) length classes by sex. These were calculated separately for the sexes and for early and late time steps in the model (Figure 19).

Table 5: Actual number of scampi measured by research staff in each time step of year between 1990–91 and 2001–02 in QMA 1 and in the core area of the fishery, and the estimated effective sample size for assumed multinomial error structure. –, no research voyages; 1991, 1990–91 fishing year, etc..

| Model<br>Year | Step 1 (Oct.–Dec.) |        |           | Step 2 (Jan.–Sept.) |        |           |
|---------------|--------------------|--------|-----------|---------------------|--------|-----------|
|               | QMA 1              | Core   | Effective | QMA 1               | Core   | Effective |
| 1991          | –                  | –      | –         | –                   | –      | –         |
| 1992          | –                  | –      | –         | –                   | –      | –         |
| 1993          | –                  | –      | –         | 7 957               | 4 628  | 1 828     |
| 1994          | –                  | –      | –         | 6 334               | 3 945  | 1 442     |
| 1995          | –                  | –      | –         | 8 133               | 4 356  | 1 472     |
| 1996          | 3 474              | 3 474  | 1 580     | 1 128               | 1 128  | 436       |
| 1997          | 7 766              | 7 766  | 2 717     | –                   | –      | –         |
| 1998          | –                  | –      | –         | 5 189               | 4 212  | 1 177     |
| 1999          | –                  | –      | –         | –                   | –      | –         |
| 2000          | –                  | –      | –         | 1 652               | 1 054  | 442       |
| 2001          | –                  | –      | –         | 1 558               | 1 558  | 595       |
| 2002          | –                  | –      | –         | 2 268               | 2 268  | 657       |
| Total         | 11 240             | 11 240 | 4 297     | 34 219              | 23 149 | 8 049     |



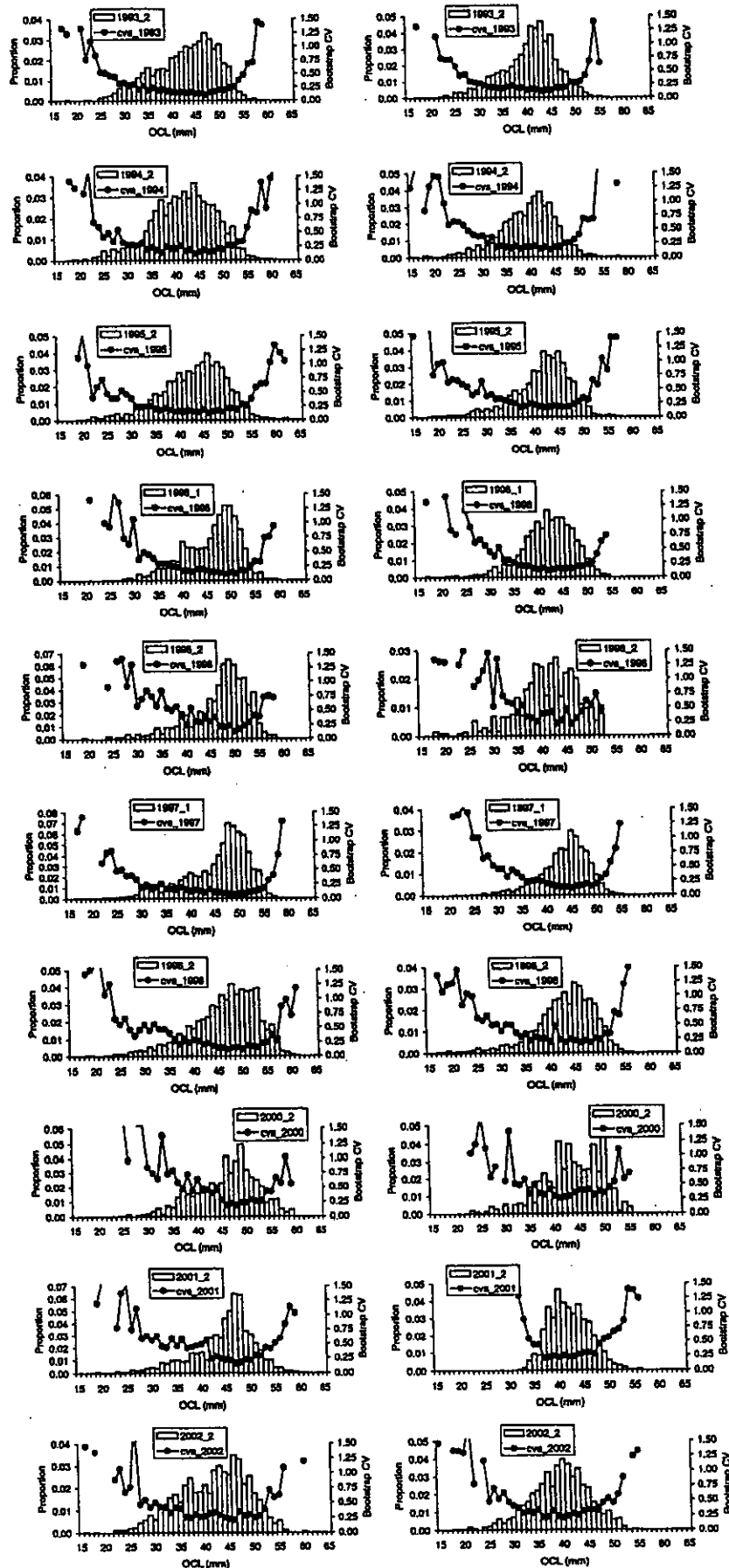


Figure 19: Research length frequency distributions for male (left) and female (right) scampi with bootstrap c.v.s estimated by NIWA catch-at-age software. "1996\_2" (e.g.) denotes model year, time-step.

## 2.4.6 Commercial catch-effort indices of relative abundance

Cryer & Coburn (2000) calculated fully standardised indices for the QMA 1 scampi fishery up to the 1997–98 fishing year. However, they found that the standardised index was very highly correlated with much simpler unstandardised indices (total catch divided by total fishing effort), and these simpler indices have been used since (e.g., Hartill & Cryer 2004). We have adopted the “G3” time series of Hartill & Cryer (2003) (groomed data excluding obvious errors and zero catches of scampi and split between the early and late steps in our model) (Figure 20) as an index of relative abundance and fitted to these within the model using nominal log-normal c.v.s. of 0.25. In general, CPUE in the modelled area was slightly higher than elsewhere in QMA 1 but showed a very similar overall trend.

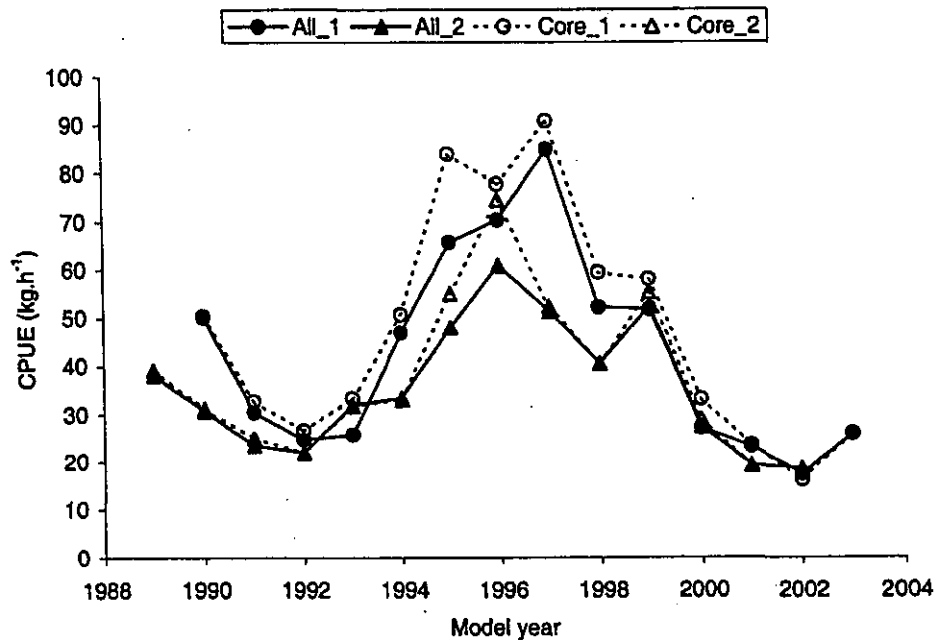


Figure 20: Unstandardised CPUE (G3 series after Hartill & Cryer 2004) for the whole of QMA 1 (“All”) and the modelled (“Core”) area in model time steps 1 and 2.

## 2.4.7 Cod-end selectivity of research and commercial trawling

Hartill et al. (2005) estimated the selectivity ogives (using asymmetrical Richards curves) of various codend and body meshes in “Florida Flyer” trawl gear in experimental fishing at 400 m depth within the modelled area in 1996. This net design is identical to that used for research trawling and is very similar to nets used throughout the commercial fishery. Research trawling uses 30 mm cod-end and 80 mm main meshes (throughout the wings, belly, body, and extension piece) and four replicate tows and a total of 1069 measurements were available from the experiment (Figure 21). Various mesh sizes are used in the commercial fishery, but our discussions with fishers (see Hartill et al. 2005) lead us to believe that combining the data from 55 and 65 mm cod-ends allied with 100 mm main meshes would be the closest approximation to an “average” commercial configuration during the modelled period. Thus, eight “replicate” tows and 1948 measurements were available from the experiment. Selection by one or other of the sampling gears is not considered to be a part of the model partition, but proportions selected by each were fitted within the model based on Richards ogives with binomial likelihoods (Bull et al. 2004). Process error (N-based) was set at 20, giving the observations relatively little weight in the model.

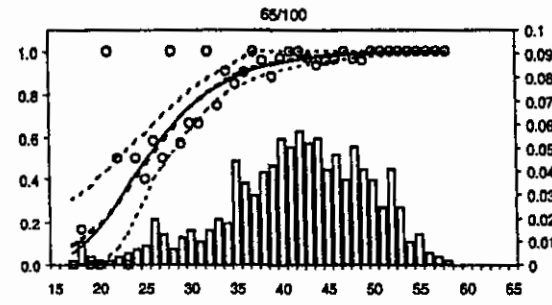
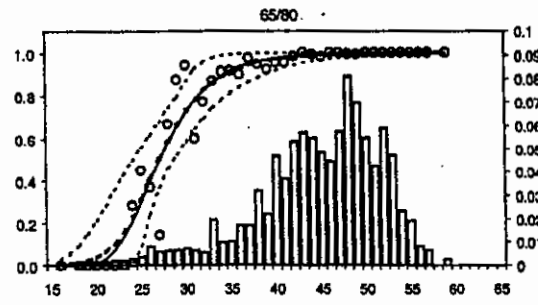
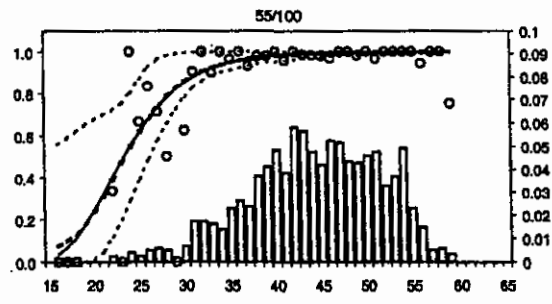
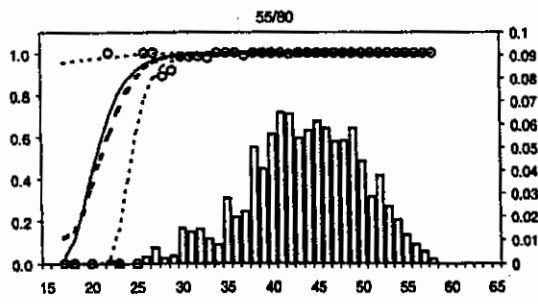
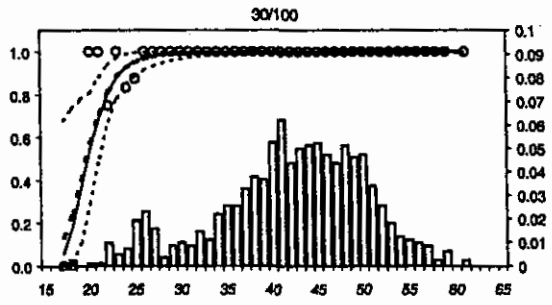
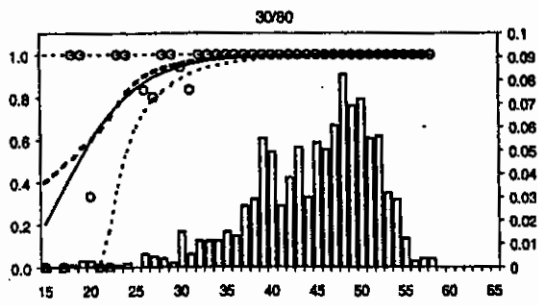
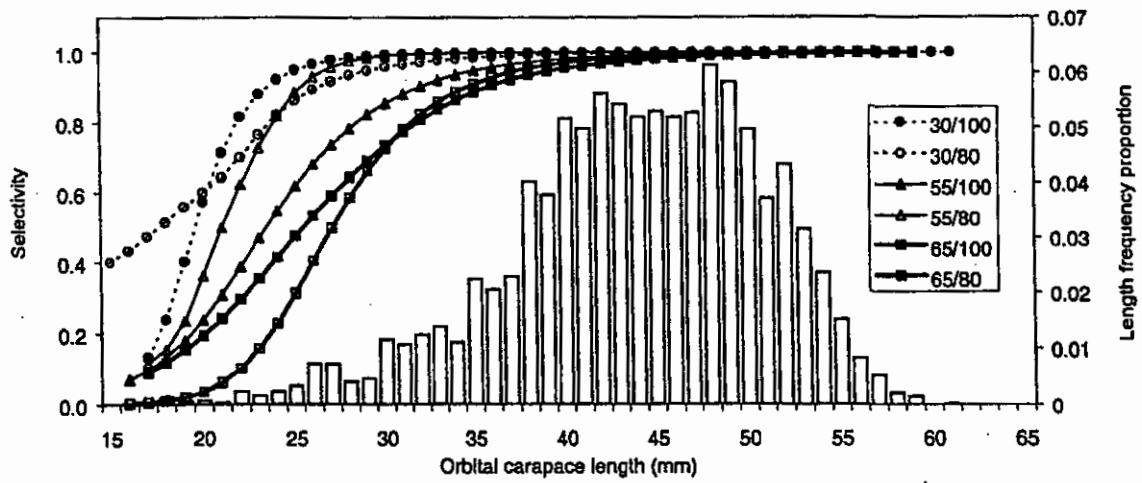


Figure 21: Estimated codend selectivity of Florida Flyer trawl gear for scampi (after Hartill et al. 2005). The top panel shows the overall length frequency distribution and estimated codend selectivity for six mesh combinations (codend/body, millimetres stretched mesh), and the smaller panels show each ogive separately with the observed data points and bootstrap 95% confidence bounds. Histograms show the length frequency distribution of animals used to fit each ogive. The 30/80 data were adopted as representative of research trawl gear and the 55/100 and 65/100 data were combined to represent "average" commercial trawl gear.

## 2.5 Model estimation and priors

Maximum Probability Density (MPD) fits were found within CASAL using a quasi-Newton optimiser and the BETADIFF automatic differentiation package (see Bull et al. (2004) and references therein). Fitting was done inside the model except for the growth model which was fitted externally and N-based process errors (see Appendix 1). CASAL was also used to run a single Monte-Carlo Markov chain (McMCMC) on the base model, with total length 1.25 million iterations (including a burn-in of 250 000 iterations) and systematic “thinning” (every 20<sup>th</sup> iteration) to 50 000 samples. MPD output was analysed using the extract and plot utilities in the CASAL and CASALUTILS libraries running under the general analytical package R (Ihaka & Gentleman (1996), available from <http://www.r-project.org>). The McMCMC was analysed using the Bayesian Output Analysis (BOA) package version 1.1.2-1 (Smith (2004), available from <http://www.public-health.uiowa/boa>), also running under R.

To reduce the number of fitted parameters, the catchability coefficients ( $q_s$ ) for commercial fishing, research trawling, and photographic surveys were assumed “nuisance” rather than free parameters. The only informative priors used in the base model were applied to  $M$  and  $q$ -Photo (Figure 22) and to the yearclass strength (YCS) vector (to constrain the variability of recruitment). The sensitivity of the model to various modelling choices was assessed using 12 sensitivity runs (MPD only) wherein informative priors were made uniform ( $M$  and  $q$ -Photo) or further restricted (YCS), the form and steepness of the spawner-recruit curve were changed, lognormal as opposed to multinomial error was used for length frequency distributions, and the codend selectivity information was omitted (Table 6).

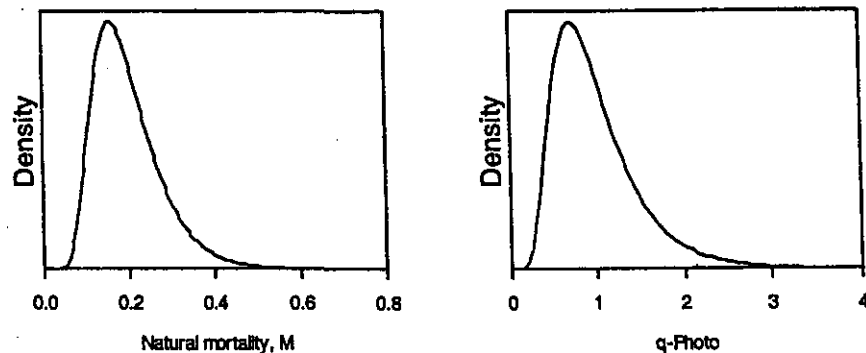


Figure 22: Informative priors in the base model.

Table 6: Summary of sensitivity runs (MPD only)

| Model      | Description   |
|------------|---|
| Base       | Base model, informative priors on $M$ and $q$ -Photo, YCS c.v. = 0.20           |
| Ricker     | Same as base except domed spawner-recruit curve                                 |
| FitPE      | Same as base except model allowed to fit process error for abundance indices    |
| FreeM      | Same as base except uniform prior on $M$  |
| Free_q     | Same as base except uniform prior on $q$ -Photo                                 |
| Free_qM    | Same as base except uniform prior on $M$ and $q$ -Photo                         |
| cvYCS10%   | Same as base except YCS cv = 0.10 (to constrain variation in recruitment)       |
| cvYCS1%    | Same as base except YCS cv = 0.01 (almost no variation in recruitment)          |
| cvYCS10%Mq | Same as base except YCS cv = 0.10 and uniform priors on $M$ and $q$ -Photo      |
| Steep0.9   | Same as base except S-R steepness of 0.90 instead of 0.75                       |
| logNLF     | Lognormal instead of multinomial error on length frequency data                 |
| PElogNLF   | Lognormal error on length frequency data and model allowed to fit process error |
| NoCodEnd   | Model not fitted to cod-end selectivity data                                    |

### 3. MODEL RESULTS

#### 3.1 Model estimates

The base model MPD fit suggested an unexploited biomass ( $B_0$ ) of about 4700 t (Figure 23, Tables 7–9) and an instantaneous rate of natural mortality ( $M$ ) of about  $0.21 \text{ yr}^{-1}$ . Year class strengths were estimated to have been consistently good in the late 1980s, consistently below average between 1990 and 1997, and about average since (Figure 24), although the model's capacity to detect variations in recruitment during that time is probably poor. This pattern of recruitment, allied with the imposed growth model, leads to an increasing spawning biomass up to the early 1990s, followed by a consistent slow decline to the end of the modelled period in 2003. The 2003 spawning biomass was estimated to be about 79% of the unexploited biomass. There were substantial correlations between the parameters defining the selectivity ogives (Table 10), most especially the strong negative correlations between the steepness and asymmetry parameters for all three ogives. There was moderate positive correlation between  $B_0$  and  $M$ .

The model was not sensitive to the assumed steepness of the stock-recruit curve, to relaxing the prior on  $M$ , or to the flexibility to fit process error to relative abundance indices (see Tables 7–9). However, it was sensitive to the choice of stock-recruit relationship, relaxing the prior on  $q$ -Photo, the amount of constraint put on recruitment variability, the choice of error structure for the length frequency observations, and the exclusion of codend selectivity-at-length observations (even though the model did not fit these data at all well). Other than the sensitivity excluding the selectivity-at-length observations (which had very high  $M$  and  $L_{50}$  for commercial fishing), none of the sensitivity fits seems implausible, yet  $B_0$  ranges widely from 4400 to 23 500 t.  $M$  is less sensitive to the modelling choices, but this may be an artefact of the imposed growth model and observed length frequency distributions. It was particularly surprising to observe the sensitivity of  $B_0$  to the error structure chosen for length frequency distributions. This suggests that rare observations in the tails of the length frequency distributions may be having a substantial effect on the model fit when log-normal error is assumed, indicating that the assumption of multinomial error structure might be preferred (as well as more "elegant").

There was substantial autocorrelation in most parameters in the initial McMC (of 50 000 samples), so this was systematically thinned further to 2000 samples. In this final chain, there was evidence of autocorrelation, "wandering", and non-stationarity only in traces for steepness and asymmetry aspects of the selectivity ogives, and these commonly failed Geweke, Raferty & Lewis, and/or Heidelberger & Welch convergence tests (Appendix 2). The posterior distributions for other parameters were roughly normal or only mildly skewed (roughly lognormal, Figure 25, Appendix 2). For most parameters, we conclude that the McMC chain was of sufficient length to estimate the posterior distributions of the base model (although this cannot capture the additional uncertainty associated with sensitivity to modelling choices).

**Table 7: Estimated parameters and quantities from the base case and sensitivity MPD fits.**

| Estimated parameters   | Base      | Ricker   | FitPE     | FreeM     | Free_q    | Free_qM   | cvYCS10%  | cvYCS1%   | cvYCS10%Mq | Steep0.9  | logNLF    | PElogNLF  | NoCodEnd  |
|------------------------|-----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|
| initialization.B0      | 4 663     | 5 908    | 4 445     | 4 703     | 10 157    | 10 372    | 6 925     | 10 813    | 23 465     | 4 753     | 6 796     | 6 967     | 7 768     |
| natural_mortality      | 0.213     | 0.217    | 0.213     | 0.214     | 0.218     | 0.218     | 0.211     | 0.207     | 0.215      | 0.214     | 0.277     | 0.256     | 0.312     |
| Photo_process_error_cv | 0.113     | 0.110    | 0.114     | 0.113     | 0.107     | 0.107     | 0.115     | 0.128     | 0.110      | 0.112     | 0.144     | 0.131     | 0.113     |
| Commercial_q           | 0.0119555 | 0.009314 | 0.0098546 | 0.0118485 | 0.0052919 | 0.0051776 | 0.0079815 | 0.0051205 | 0.002278   | 0.01171   | 0.0070781 | 0.0070126 | 0.024158  |
| PhotoSurvey_q          | 0.655     | 0.513    | 0.691     | 0.649     | 0.283     | 0.277     | 0.417     | 0.252     | 0.116      | 0.642     | 0.446     | 0.425     | 0.331     |
| TrawlSurvey_q          | 0.002916  | 0.00227  | 0.0024425 | 0.0028892 | 0.0012836 | 0.001256  | 0.0019388 | 0.0012572 | 0.0005502  | 0.0028558 | 0.0017996 | 0.0017834 | 0.0023143 |
| R0                     | 3.76E+07  | 4.93E+07 | 3.58E+07  | 3.80E+07  | 8.55E+07  | 8.73E+07  | 5.45E+07  | 8.19E+07  | 1.92E+08   | 3.85E+07  | 9.81E+07  | 8.43E+07  | 1.49E+08  |
| YCS_1985               | 1.574     | 1.609    | 1.581     | 1.571     | 1.526     | 1.525     | 1.241     | 1.004     | 1.228      | 1.577     | 2.399     | 2.193     | 1.215     |
| YCS_1986               | 1.526     | 1.522    | 1.529     | 1.524     | 1.509     | 1.504     | 1.400     | 1.008     | 1.387      | 1.525     | 1.898     | 1.854     | 1.564     |
| YCS_1987               | 1.843     | 1.841    | 1.853     | 1.846     | 1.811     | 1.813     | 1.551     | 1.010     | 1.536      | 1.843     | 2.032     | 1.432     | 1.978     |
| YCS_1988               | 1.100     | 1.095    | 1.104     | 1.099     | 1.094     | 1.095     | 1.120     | 1.005     | 1.112      | 1.101     | 1.094     | 1.295     | 1.077     |
| YCS_1989               | 0.992     | 0.985    | 0.996     | 0.992     | 0.989     | 0.989     | 1.000     | 1.001     | 1.000      | 0.992     | 1.411     | 1.235     | 0.901     |
| YCS_1990               | 0.880     | 0.870    | 0.883     | 0.879     | 0.881     | 0.881     | 0.903     | 0.997     | 0.905      | 0.880     | 1.023     | 0.907     | 0.935     |
| YCS_1991               | 0.665     | 0.651    | 0.666     | 0.664     | 0.666     | 0.666     | 0.762     | 0.992     | 0.764      | 0.664     | 0.778     | 0.857     | 0.740     |
| YCS_1992               | 0.605     | 0.588    | 0.605     | 0.604     | 0.607     | 0.607     | 0.721     | 0.990     | 0.725      | 0.604     | 0.673     | 0.685     | 0.661     |
| YCS_1993               | 0.654     | 0.635    | 0.652     | 0.654     | 0.658     | 0.659     | 0.753     | 0.991     | 0.757      | 0.654     | 0.584     | 0.622     | 0.686     |
| YCS_1994               | 0.663     | 0.643    | 0.659     | 0.663     | 0.669     | 0.669     | 0.782     | 0.992     | 0.788      | 0.662     | 0.529     | 0.613     | 0.729     |
| YCS_1995               | 0.850     | 0.832    | 0.845     | 0.850     | 0.860     | 0.860     | 0.890     | 0.995     | 0.899      | 0.849     | 0.593     | 0.643     | 0.934     |
| YCS_1996               | 0.761     | 0.747    | 0.754     | 0.760     | 0.770     | 0.771     | 0.864     | 0.995     | 0.870      | 0.760     | 0.701     | 0.826     | 0.912     |
| YCS_1997               | 0.752     | 0.742    | 0.746     | 0.752     | 0.762     | 0.765     | 0.877     | 0.996     | 0.884      | 0.752     | 0.538     | 0.583     | 0.845     |
| YCS_1998               | 0.970     | 0.965    | 0.962     | 0.972     | 0.990     | 0.985     | 1.027     | 0.999     | 1.039      | 0.972     | 0.824     | 0.887     | 1.011     |
| YCS_1999               | 1.160     | 1.166    | 1.152     | 1.157     | 1.180     | 1.190     | 1.117     | 0.999     | 1.126      | 1.159     | 0.676     | 0.795     | 1.039     |
| YCS_2000               | 1.027     | 1.057    | 1.021     | 1.033     | 1.053     | 1.046     | 1.026     | 0.998     | 1.036      | 1.035     | 0.730     | 0.841     | 0.907     |
| YCS_2001               | 0.913     | 0.973    | 0.914     | 0.910     | 0.928     | 0.923     | 0.958     | 0.996     | 0.962      | 0.921     | 0.708     | 0.809     | 0.852     |
| YCS_2002               | 1.021     | 1.124    | 1.029     | 1.024     | 1.037     | 1.040     | 0.980     | 0.996     | 0.987      | 1.037     | 0.865     | 0.960     | 1.004     |
| Maturity50             | 30.31     | 30.31    | 30.31     | 30.31     | 30.31     | 30.31     | 30.31     | 30.31     | 30.31      | 30.31     | 30.31     | 30.31     | 30.31     |
| MaturityTo95           | 7.16      | 7.17     | 7.16      | 7.16      | 7.17      | 7.16      | 7.17      | 7.16      | 7.17       | 7.16      | 7.17      | 7.16      | 7.17      |
| Comm50                 | 32.66     | 32.64    | 32.67     | 32.67     | 32.63     | 32.64     | 32.75     | 32.61     | 32.68      | 32.66     | 31.71     | 30.74     | 51.69     |
| CommTo95               | 8.67      | 8.64     | 8.73      | 8.66      | 8.64      | 8.58      | 8.37      | 7.90      | 8.51       | 8.66      | 6.33      | 5.96      | 19.00     |
| CommAsy                | 1.17      | 1.17     | 1.16      | 1.17      | 1.16      | 1.18      | 1.24      | 1.32      | 1.18       | 1.17      | 1.00      | 1.00      | 1.00      |
| Rsch50                 | 32.51     | 32.48    | 32.51     | 32.51     | 32.50     | 32.49     | 32.91     | 33.87     | 32.91      | 32.51     | 32.62     | 31.81     | 40.18     |
| RschTo95               | 5.03      | 5.00     | 5.00      | 5.03      | 4.98      | 5.03      | 5.19      | 5.26      | 5.04       | 5.02      | 8.85      | 8.28      | 13.18     |
| RschAsy                | 3.39      | 3.39     | 3.42      | 3.38      | 3.43      | 3.36      | 3.38      | 3.62      | 3.57       | 3.40      | 1.00      | 1.00      | 1.00      |
| Photo50                | 18.80     | 18.98    | 18.80     | 18.81     | 18.78     | 18.80     | 18.58     | 18.33     | 18.59      | 18.81     | 19.83     | 19.60     | 20.69     |
| PhotoTo95              | 4.27      | 4.33     | 4.29      | 4.28      | 4.29      | 4.31      | 4.15      | 4.00      | 4.18       | 4.26      | 6.25      | 6.13      | 5.74      |
| PhotoAsy               | 2.19      | 2.15     | 2.20      | 2.19      | 2.17      | 2.16      | 2.23      | 2.30      | 2.24       | 2.19      | 2.24      | 2.36      | 1.75      |
| B2003                  | 3 674     | 4 717    | 3 472     | 3 709     | 8 565     | 8 761     | 5 984     | 10 304    | 21 443     | 3 753     | 4 980     | 5 426     | 6 702     |
| B2003/B1985            | 0.79      | 0.80     | 0.78      | 0.79      | 0.84      | 0.84      | 0.86      | 0.95      | 0.91       | 0.79      | 0.73      | 0.78      | 0.86      |

Table 8: Priors and assumptions for the base case MPD fit and sensitivity runs. Informative priors (with log-normal distribution) are specified as LN(x,y) where x is the mean and y is the cv of the distribution. "Fitted" means fitted within the model, "Estimated" means estimated outside the model using some other process.

| Assumptions:      | Form of Stock-recruit relationship | Steepness of Stock-recruit relationship | Prior on Bzero | Prior on M  | Prior on q-Photo | Prior on q-Comm | Prior on q-Rsch | Priors on YCS | Error structure on LFS | Fit to cod-end selectivity data? | Sampling (cv) CPUE | Sampling (cv) Trawlsurvey | Sampling (cv) Photosurvey | Process error (cv) CPUE | Process error (cv) Trawlsurvey | Process error (cv) Photosurvey | Process error (N) Comm_LF | Process error (N) Rsch_LF | Process error (N) Photo_LF | Priors on Maturity | Priors on Rsch_sel | Priors on Comm_sel | Process error (N) Rsch_sel | Process error (N) Comm_sel | Penalty scalar, catch not taken | Penalty scalar, YCS not 1.0 |
|-------------------|------------------------------------|---|----------------|-------------|------------------|-----------------|-----------------|---------------|------------------------|----------------------------------|--------------------|---------------------------|---------------------------|-------------------------|--------------------------------|--------------------------------|---------------------------|---------------------------|----------------------------|--------------------|--------------------|--------------------|----------------------------|----------------------------|---------------------------------|-----------------------------|
| Base              | B-H                                | 0.75                                    | Uniform        | LN(0.2,0.5) | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| Ricker            | Ricker                             | 0.75                                    | Uniform        | LN(0.2,0.5) | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| FreeM             | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| Free_q            | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(0.2,0.5)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| Free_qM           | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(0.2,0.5)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| cvYCS10%          | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| cvYCS10% YCS10%mq | B-H                                | 0.75                                    | Uniform        | Uniform     | Uniform          | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| Sleep0.9          | B-H                                | 0.9                                     | Uniform        | Uniform     | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| logNLF            | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | N/A                       | Fitted CV                 | N/A                        | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| PElogNLF          | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(1.0,0.4)      | Uniform         | Uniform         | Uniform       | Multinomial            | Yes                              | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | N/A                       | Fitted CV                 | N/A                        | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |
| NoCodEnd          | B-H                                | 0.75                                    | Uniform        | Uniform     | LN(0.2,0.5)      | Uniform         | Uniform         | Uniform       | Multinomial            | No                               | 0.25               | Estimated                 | Fitted                    | 1.0                     | 1.0                            | Estimated                      | 500                       | Estimated                 | Estimated                  | Uniform            | Uniform            | Uniform            | 20                         | 20                         | 1000                            | 100                         |

**Table 9: Likelihood components for the base case MPD fit and sensitivity runs.**

| Likelihood components               | Base            | Ricker          | FitPE           | FreeM           | Free_q          | Free_qM         | cvYCS10%        | cvYCS1%         | cvYCS10%Mq      | Steep0.9        | logNLF          | PElogNLF        | NoCodEnd        |
|-------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| <b>Abundance indices:</b>           |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| CPUE-Commercial-Jan                 | -0.38947        | -0.38217        | -4.37697        | -0.38950        | -0.40017        | -0.40070        | -0.42449        | -0.42277        | -0.42850        | -0.38915        | -0.24655        | -0.32054        | -0.49551        |
| CPUE-Commercial-Oct                 | 0.00361         | 0.00020         | -3.28335        | 0.00365         | 0.03085         | 0.03124         | 0.13009         | 0.41816         | 0.15449         | 0.00370         | -0.14229        | -0.05151        | -0.01666        |
| PhotoSurvey                         | -6.44501        | -6.50633        | -6.43202        | -6.44719        | -6.532          | -6.53377        | -6.36912        | -6.1313         | -6.43186        | -6.45187        | -5.92508        | -6.16092        | -6.39228        |
| TrawlSurvey                         | -0.35248        | -0.35696        | -2.75742        | -0.35215        | -0.31510        | -0.31393        | -0.21325        | 0.05544         | -0.18329        | -0.35226        | -0.59769        | -0.48802        | -0.35600        |
| <b>Proportions and selectivity:</b> |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| PhotoProportionAtLength-Jan         | 302.93          | 302.80          | 303.26          | 302.83          | 303.78          | 303.79          | 303.45          | 309.73          | 304.78          | 302.85          | 24.608          | 23.85           | 257.70          |
| TrawlProportionAtLength-Jan         | 1120.56         | 1121.3          | 1119.75         | 1120.4          | 1121.16         | 1121.35         | 1119.08         | 1138.47         | 1119.45         | 1120.49         | 609.182         | 571.16          | 1055.04         |
| TrawlProportionAtLength-Oct         | 253.57          | 252.26          | 253.50          | 253.54          | 253.53          | 253.58          | 262.94          | 286.63          | 262.68          | 253.45          | 136.33          | 91.606          | 237.75          |
| CommercialCatchLengthJan            | 1151.90         | 1153.06         | 1152.16         | 1151.91         | 1152.50         | 1152.08         | 1150.82         | 1175.83         | 1151.30         | 1152.02         | 928.143         | 827.28          | 1166.17         |
| CommercialCatchLengthOct            | 568.69          | 567.12          | 568.64          | 568.65          | 567.94          | 568.07          | 580.41          | 618.45          | 579.36          | 568.56          | 694.88          | 650.22          | 614.03          |
| Cryer&Oliver_maturity               | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          | 47.289          |
| SHSP05_expt_comm.                   | 99.038          | 98.831          | 99.086          | 99.252          | 98.686          | 98.867          | 100.657         | 99.152          | 100.042         | 99.102          | 102.558         | 89.351          | 0               |
| SHSP05_expt_rschn                   | 71.502          | 71.198          | 71.476          | 71.589          | 71.417          | 71.304          | 76.627          | 89.706          | 76.207          | 71.563          | 87.615          | 76.399          | 0               |
| <b>Priors:</b>                      |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Prior_on_initialization.B0          | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_natural_mortality          | -1.4786         | -1.4483         | -1.4802         | 0               | -1.4390         | 0               | -1.5010         | -1.5331         | 0               | -1.4759         | -0.7503         | -1.0111         | -0.2629         |
| Prior_on_Photo_processorerror       | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_recruitment.YCS            | 21.6827         | 18.6853         | 22.0400         | 21.6998         | 20.7261         | 20.7062         | 38.5439         | 2.1536          | 37.0244         | 21.4797         | 47.5119         | 31.253          | 16.0052         |
| Prior_on_maturity_props.all         | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_Comm_selectivity           | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_Rsch_selectivity           | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_Photo_selectivity          | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_Commercial_q               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| Prior_on_Photo_q                    | -0.20580        | 0.024845        | -0.22045        | -0.20191        | 0               | 0               | 0.43180         | 2.22315         | 0               | -0.19659        | 0.27575         | 0.38462         | 1.11294         |
| Prior_on_Rsch_q                     | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| <b>Penalties:</b>                   |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| OctCatchMustBeTaken                 | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| JanCatchMustBeTaken                 | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               | 0               |
| YCS_average_1                       | 0.00177         | 0.00743         | 0.00190         | 0.00118         | 0.00802         | 0.00484         | 0.00383         | 0.000001        | 0.00314         | 0.00288         | 0.16785         | 0.01538         | 0.01730         |
| <b>Likelihood totals for:</b>       |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Data                                | 3608.303        | 3606.622        | 3598.328        | 3608.292        | 3609.100        | 3609.121        | 3634.413        | 3759.187        | 3634.233        | 3608.153        | 2623.705        | 2370.151        | 3370.729        |
| Priors                              | 19.998          | 17.262          | 20.339          | 21.498          | 19.287          | 20.706          | 37.475          | 2.844           | 37.024          | 19.807          | 47.037          | 30.627          | 16.855          |
| Penalties                           | 0.002           | 0.007           | 0.002           | 0.001           | 0.008           | 0.005           | 0.004           | 0.000           | 0.003           | 0.003           | 0.168           | 0.015           | 0.017           |
| <b>Total</b>                        | <b>3628.303</b> | <b>3623.891</b> | <b>3618.669</b> | <b>3629.791</b> | <b>3628.396</b> | <b>3629.833</b> | <b>3671.891</b> | <b>3762.031</b> | <b>3671.261</b> | <b>3627.963</b> | <b>2670.910</b> | <b>2400.793</b> | <b>3387.601</b> |





Figure 24: Mean and 90% credible ranges (from posterior distributions) for model estimates of year-class strength in the base case. Medians are shown as open dots and means as horizontal bars. Average recruitment over the time period is shown as the horizontal line.

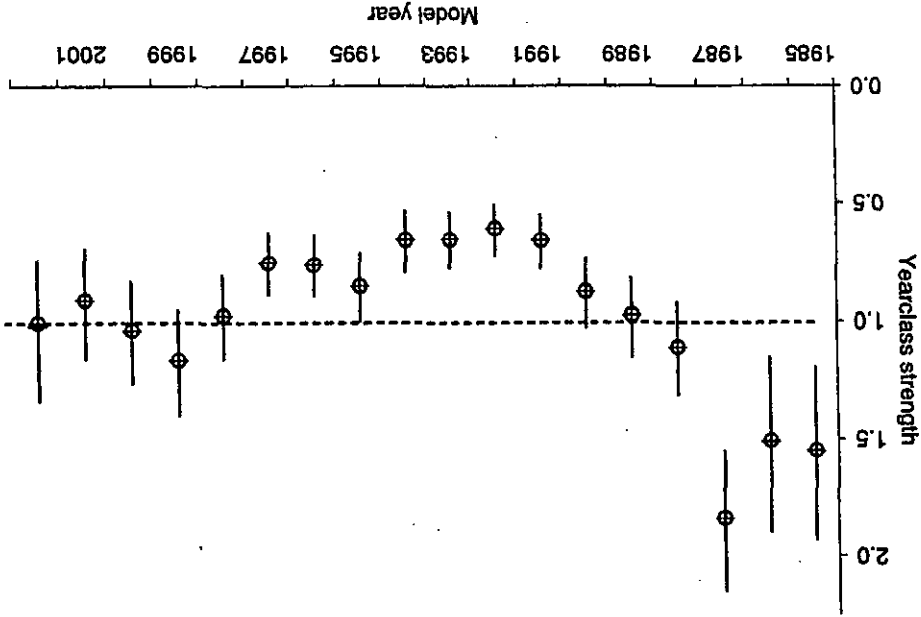
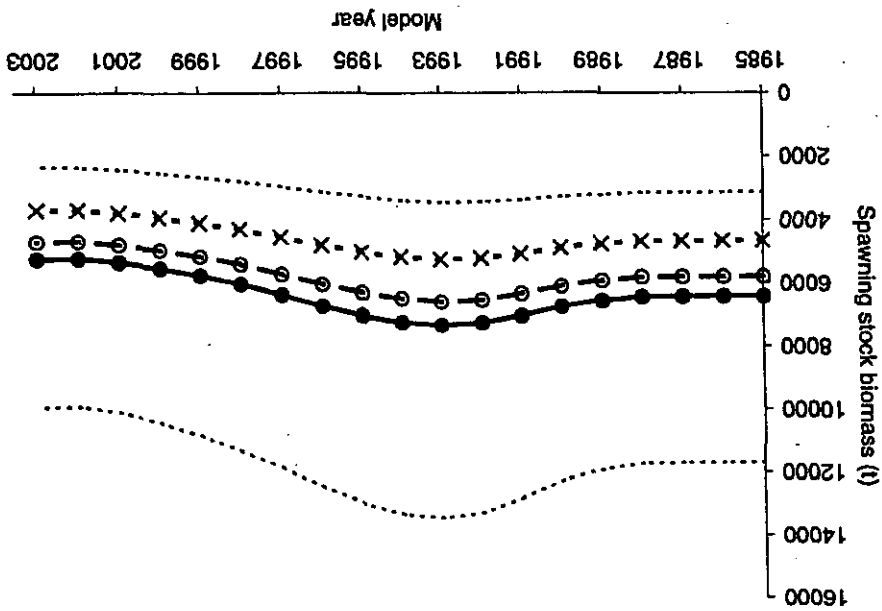


Figure 23: Base case trajectory of spawning stock biomass in the modelled part of the QMA I scampi fishery. The mean and median of the posterior distribution are shown as solid and dashed heavy lines, respectively, and the 90% credible range as light dotted lines. The MPD biomass trajectory is shown with a heavy dotted line and crosses.



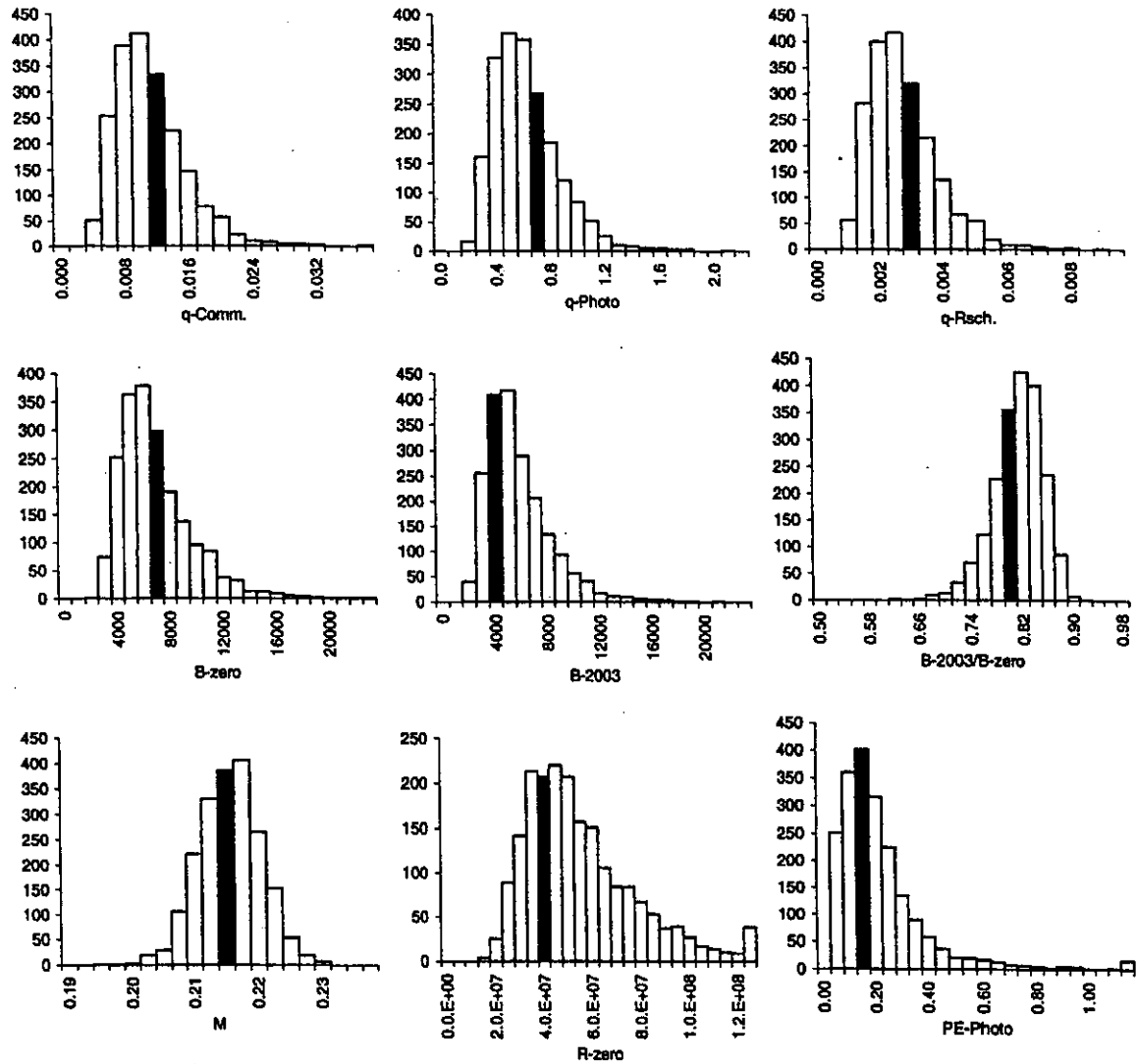


Figure 25: Estimated posterior distributions for key estimated, derived, and “nuisance” (q), parameters from the base model. In each case, the data bin containing the MPD is shaded.

### 3.2 Model fits to data

None of the models tested fitted all of the data well. Fits to the commercial CPUE and research trawl abundance indices were always very poor (Figure 26) and the model could not reproduce either the wide variability or the cyclical pattern that characterised both. If given the opportunity to fit process error, the model fitted “additional” c.v.s of 0.4–0.5 suggesting that these time series are not easily reconciled with the rest of the data or the constraints and assumptions of the model. This was not a surprise because much previous work had suggested that trawl-based catchability varied substantially between years for scampi. For the base model, therefore, we chose to increase the process error c.v.s on these data still further to 1.0 and they are largely ignored in the model. The fit to the photographic survey indices of abundance or biomass was better, although the time series is still quite short. If given the opportunity to fit process error, the model fitted an “additional” c.v. of only about 0.1 suggesting that this series is consistent with the bulk of the data and the model. The 2000 photographic survey seems an outlier and the assumptions and calculations used to generate the data point should be checked.

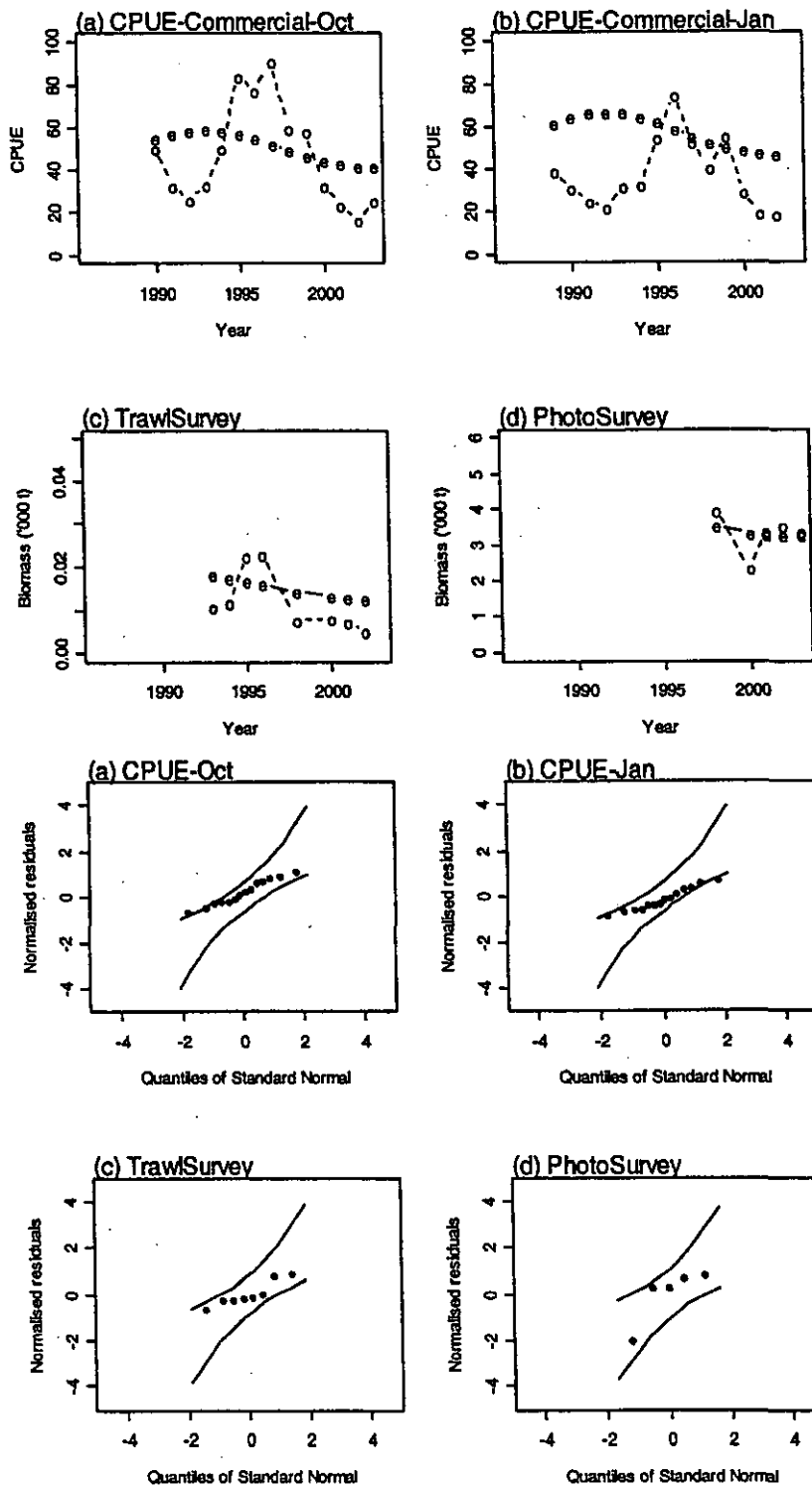


Figure 26: Fits to relative biomass indices (top) o, observed; e, fitted) and q-q diagnostic plots (bottom).

The general form of the fits to the research trawl length frequency distributions were reasonable (Figures 27–29), but the model did not reproduce the observed variation in sex ratio (Figure 30). This failing was apparent in the fits to the commercial (observer) length frequency distributions too (see Figure 30), but the model had additional problems fitting to the much wider between-year variability in the commercial data (and, especially, the preponderance of very large animals in early 1993 and 1996, and late 1992 and 1997, Figures 31 and 32). This is not surprising because commercial fishers are likely to target specific areas and/or depth bands to meet particular requirements (for large size or particularly high catch rates, or to shelter from poor weather, for instance) whereas research tows are randomised throughout the sampled area and are more likely to represent the “average condition”. In addition, experienced scientific staff probably generate more precise measurements of scampi with fewer errors than observers who may work on the species only very rarely. If given the opportunity to fit process error, the model fitted only a modest amount to the research data, but fitted so much to the commercial length frequency distributions that they were effectively ignored in the model. This flexibility to “ignore” the catch at length allowed the model to fit an implausibly high  $L_{50}$  for the commercial selectivity ogive. The fit to the length frequency distributions derived from photographic surveys was only fair (Figure 33), but perhaps as good as might be expected given all the uncertainties in their derivation. If given the opportunity to fit process error, the model did not add any to the observed (bootstrapped) error.

The fit to the observed female maturity at length was excellent (Figure 34a), but there is little consequence for the model; fitting the maturity ogive does not require compromises to be made in other fits. Conversely, the fits to the selectivity at length data were very poor (Figures 34 b and c) and the model favoured much higher estimates of  $L_{50}$  for both research and commercial trawling than were observed in the codend selectivity study (Hartill et al. 2005). Despite these poor fits, excluding the selectivity at length data caused the model to favour values of  $L_{50}$  that were close to the maximum observed size for scampi, and we considered these to be implausible. We infer that the cod-end selectivity experiment measured a “different” selectivity from that used in the model. The overall selectivity of commercial or research trawling for a “cryptic” animal like scampi depends on the behaviour of the animal as well as the characteristics of the gear, in that scampi can be caught by trawl only when they are out of their burrows. If this behaviour has a length-based component (e.g., large scampi emerge from their burrows more frequently than small scampi), then this will affect the length frequency distribution of animals encountered by the gear. Hartill et al.’s (2005) selectivity experiment measured the retention of scampi encountering the codend, effectively ignoring the behavioural component and any “pre-selection” by the wings and body of the net. Thus, the overall selectivity of commercial or research trawling should be the product of emergence, any “pre-selection”, and codend selectivity ogives, but a full assessment of this was beyond the scope of this project. The fitted selectivity ogive for photographic sampling (Figure 34d) effectively describes the minimum size of burrows that are accepted as likely to be scampi burrows by readers. In part, this is defined by an (approximate) minimum width of 50 mm specified in the screening protocol, but there is also a tendency for small burrows to look “less characteristic” of scampi than larger burrows, even for those burrows that can be seen to be inhabited by scampi. The fitted  $L_{50}$  of slightly under 20 mm OCL is broadly consistent with the “minimum acceptable width” of 50 mm (see Figure 14).

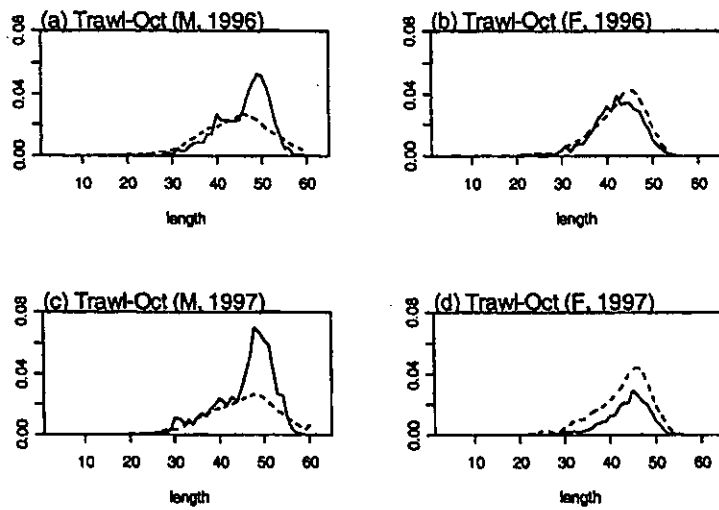


Figure 27: Observed (solid lines) and fitted (dashed lines) length frequency distributions from research trawling in time step 1 (October to December).

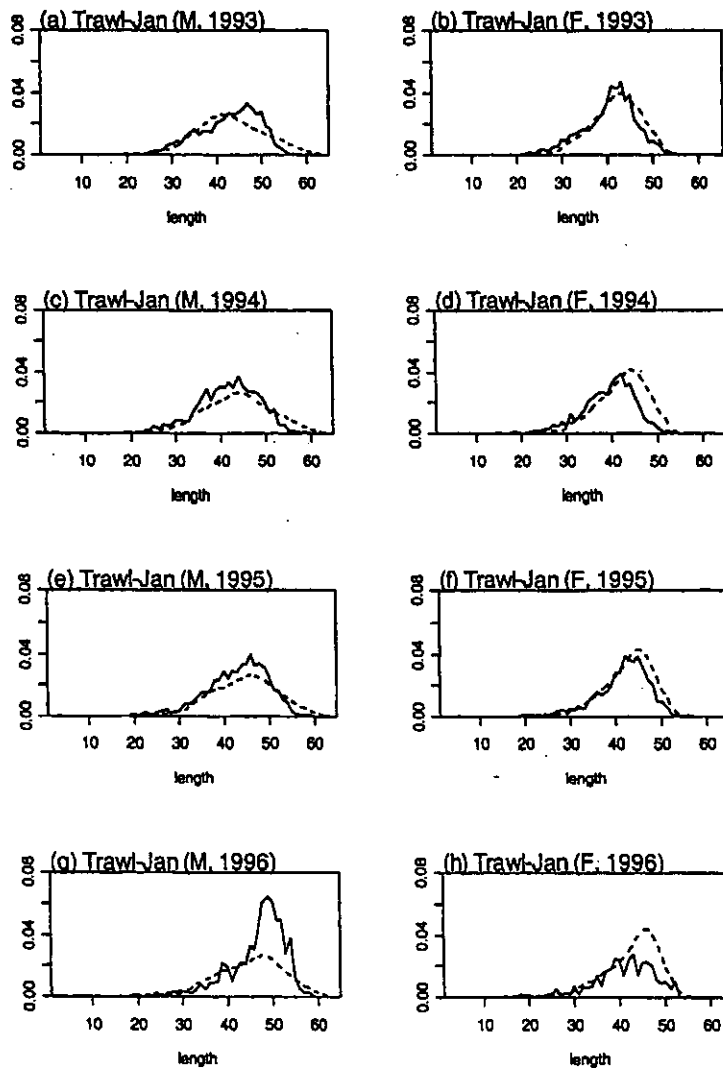


Figure 28: Observed (solid lines) and fitted (dashed lines) length frequency distributions from research trawling in time step 2 (January to September, 1993 to 1996).

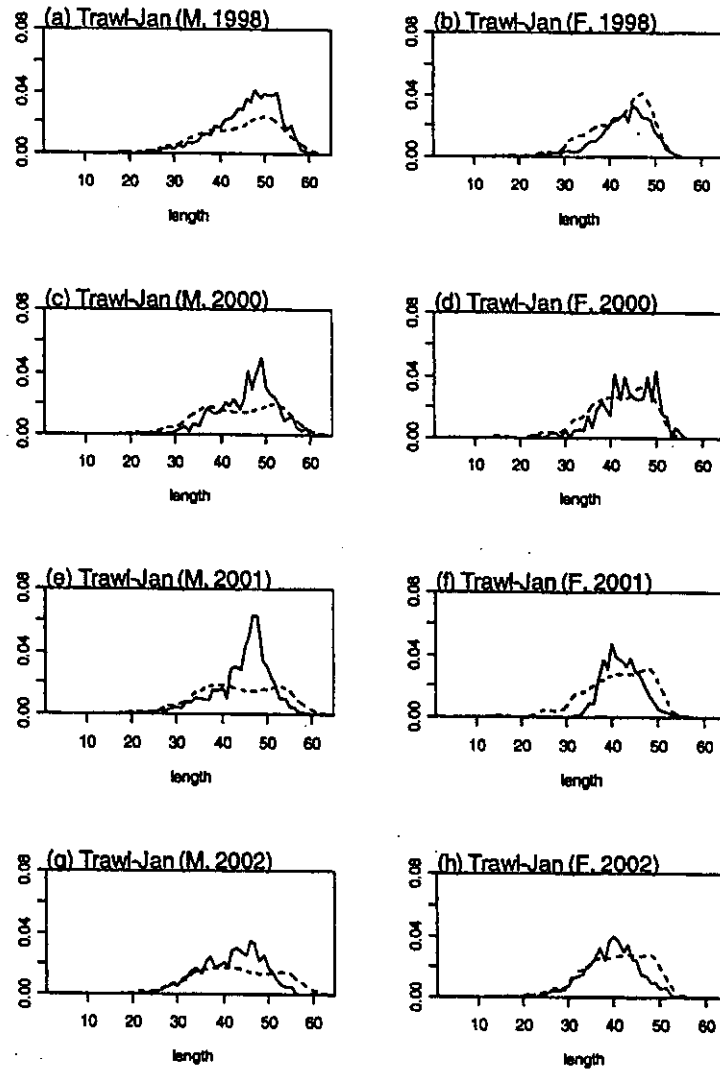


Figure 29: Observed (solid lines) and fitted (dashed lines) length frequency distributions from research trawling in time step 2 (January to September, 1998 to 2002).

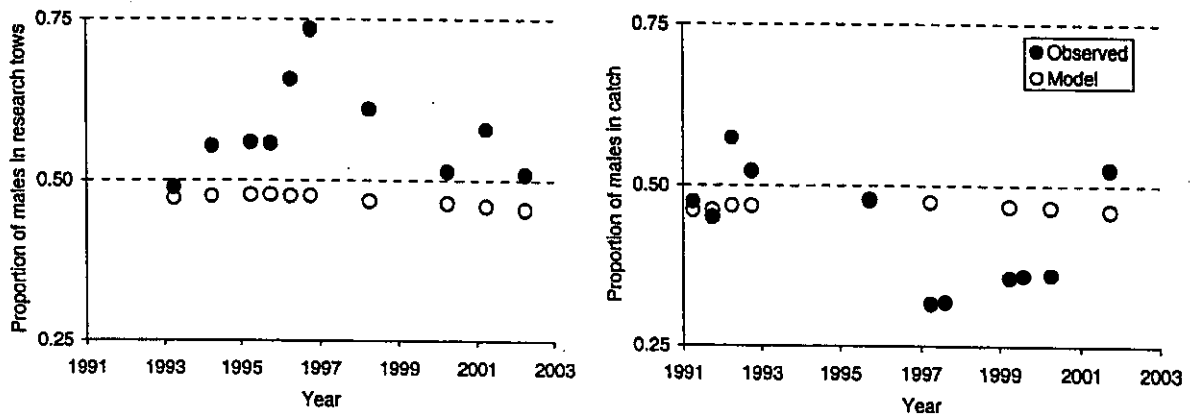


Figure 30: Observed (solid) and modelled (open) proportion of males in research trawl data (left) and in the commercial catch (as estimated by observers, right).

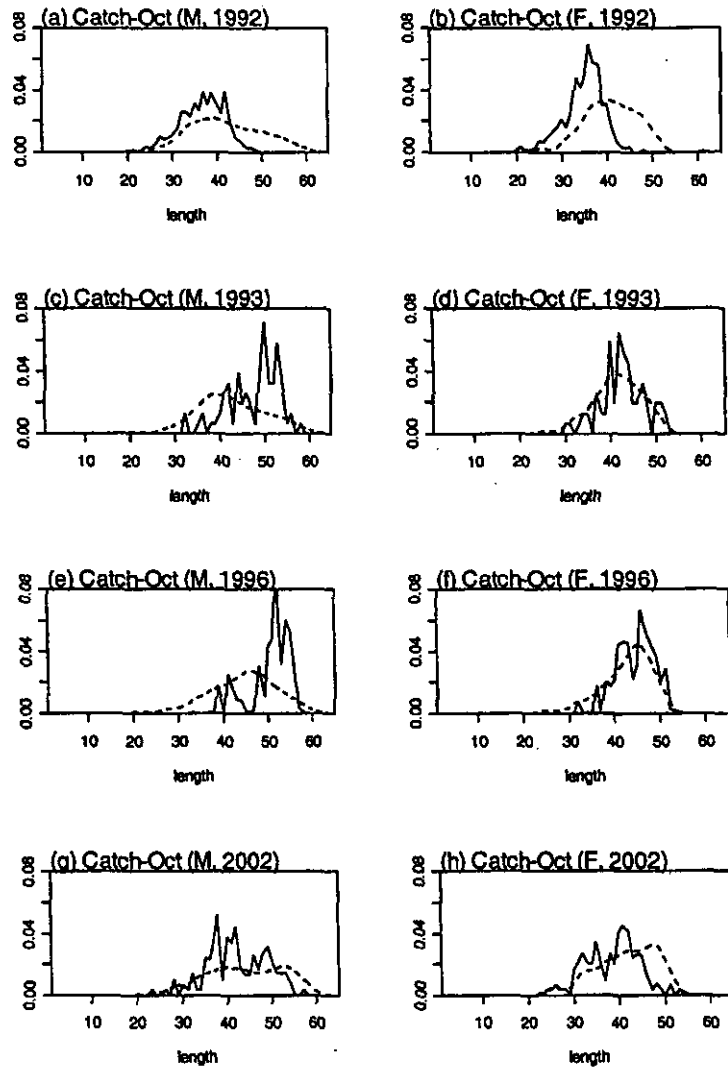


Figure 31: Observed (solid lines) and fitted (dashed lines) commercial catch at length in time step 1 (October to December, 1992 to 2002).

Likelihood profiling (by fixing key parameters at a range of values and refitting the model at each level) suggested that a wide range of biomass levels produced similar likelihoods (its profile was relatively flat) (Figure 35), but only a narrow range of  $M$  was tolerated (its profile was steep). Given the major assumptions of the model (including the imposed growth model) and the observed data, an unexploited biomass of less than 1000 t, or an instantaneous rate natural mortality much different from the MPD estimate of  $0.21 \text{ yr}^{-1}$  seem most unlikely. The likelihood profile for  $B_0$  did not respond very strongly to any of the data sets, but was strongly driven by the priors at very low biomass. Penalties were never invoked. Conversely, the likelihood profile for  $M$  was strongly affected by most of the length frequency data sets (though in conflicting directions) and by the priors and penalties.



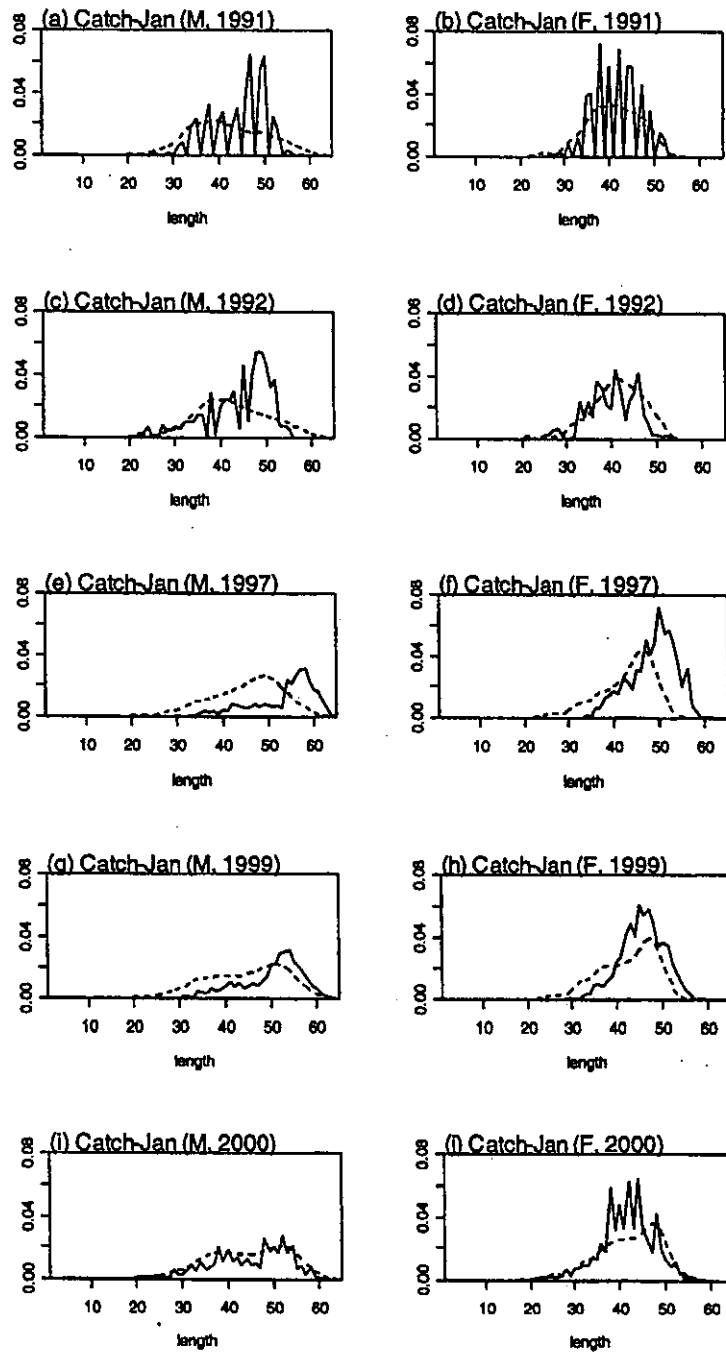


Figure 32: Observed (solid lines) and fitted (dashed lines) commercial catch at length in time step 2 (January to September, 1991 to 2000).

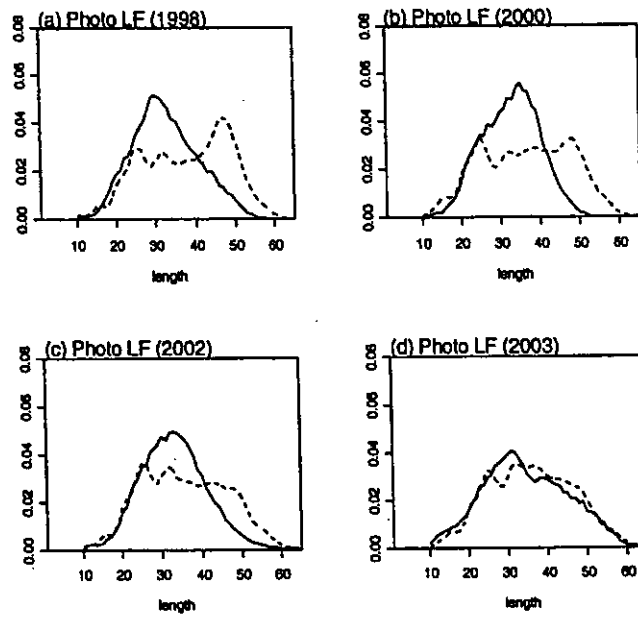


Figure 33: Observed (solid lines) and fitted (dashed lines) length frequency distributions from photographic surveys.

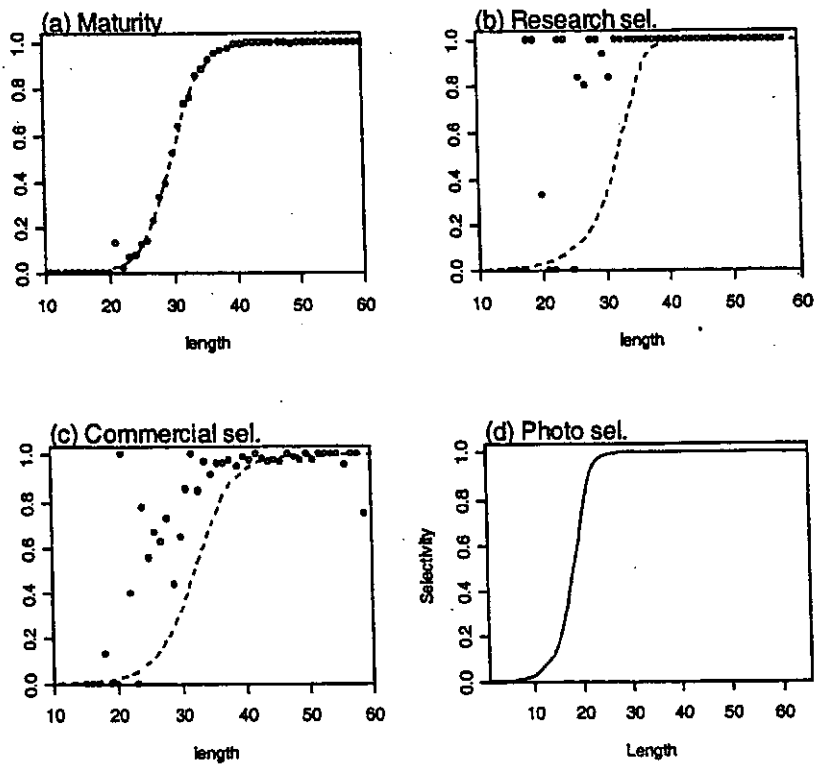


Figure 34: Fitted ogives (lines) and observed data (dots) for maturity at length and selectivity at length for commercial and research trawling, and for photographic surveys.

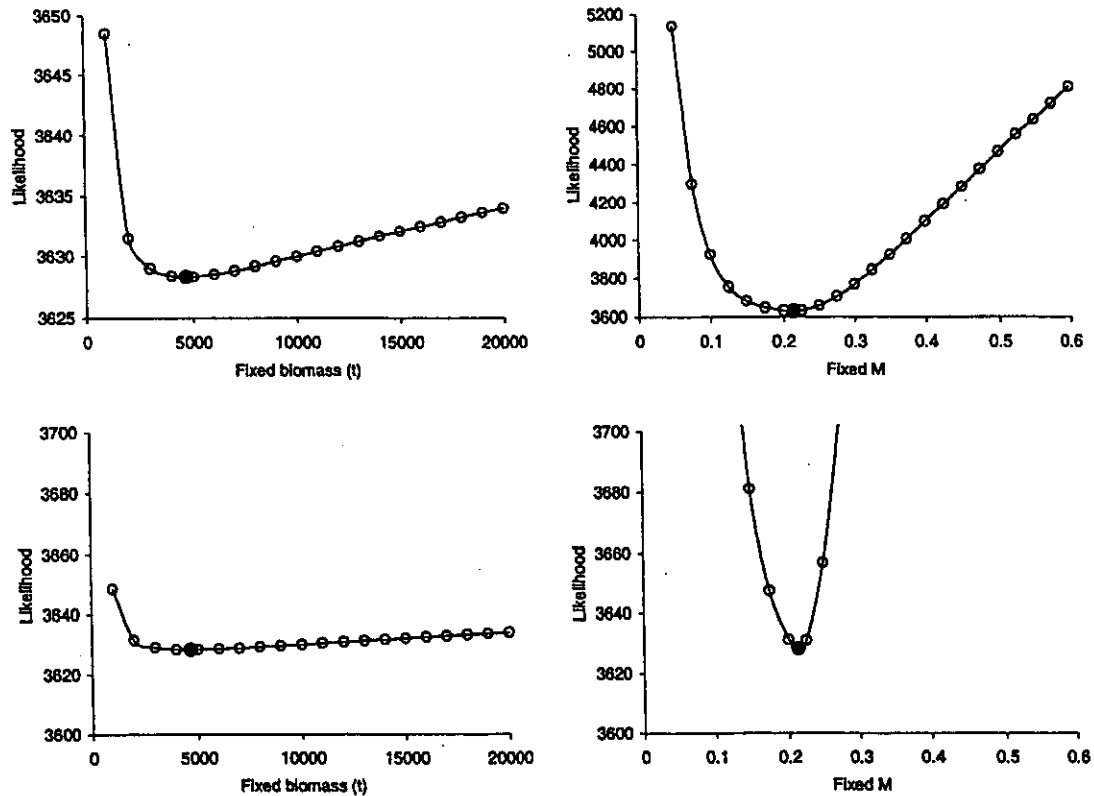


Figure 35: Likelihood profiles for the base model when  $B_0$  (left) or  $M$  are fixed in the model. The top two panels are on likelihood scales suited to each profile, the bottom two on identical scales. MPD fits are shown with the solid dots.

#### 4. DISCUSSION

The model presented here is essentially a “first cut” of a length-based stock assessment model for scampi, although a provisional model was discussed by the Shellfish Fishery Assessment Working Group in March 2004 and some substantial improvements have been made since. The stock in QMA 1 between the Mercury Islands and White Island, 300–500 m depth, was selected for this first model because it has been fished for longest, and substantially more information is available from a variety of sources (particularly from photographic surveys that are independent of both the fishery and the trawl method). Models for other areas could be developed using the experience gained in this area.

Bearing in mind the early stage of development, the base model suggests that the spawning stock biomass of scampi between the Mercury Islands and White Island in 1985, 300–500 m depth, was in the region of 5000 t. This result is sensitive to modelling assumptions and choices, however, and a wide range of biomass between 2000 and 10 000 t or more seems plausible. The estimate of current stock status ( $B_{2003} / B_{1985}$ ) is less sensitive to modelling choices, and is relatively stable at 75–90% of the unfished spawning biomass. The model seems greatly constrained in its choice of values for natural mortality, and this is probably driven by the imposed growth model in conjunction with the various length frequency distributions (which appear to favour widely differing values of  $M$ ). Looking more deeply into the fits, the model clearly does not reproduce the characteristic cyclical pattern of commercial CPUE and research trawling, nor the marked changes in observed sex ratio between years. We think these are consequences of the emergence behaviour of scampi which we suggest varies with size, sex, time of day, season, and between years. This is always going to present problems for population modelling, especially using short time series.

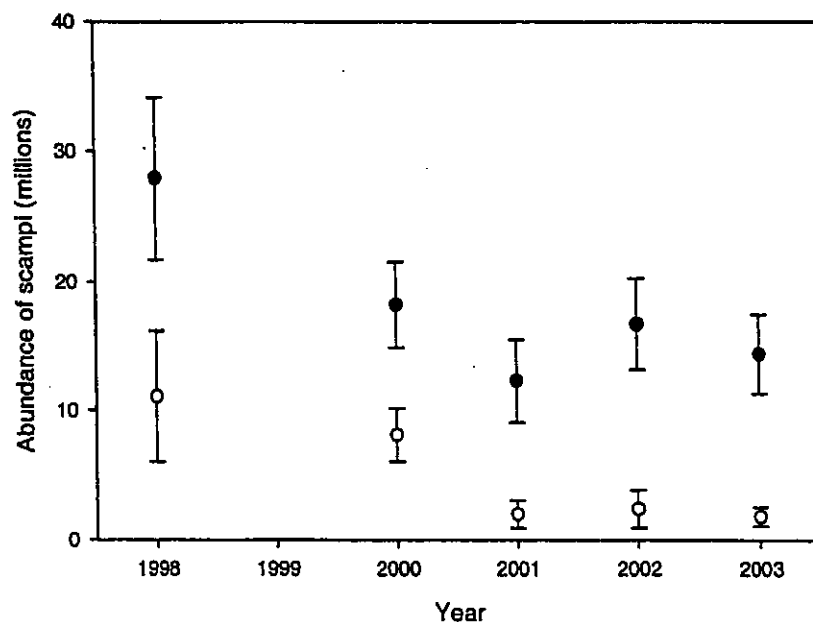
**Table 11: Additions to likelihood components (over and above the minimum for each) for each data set and for the priors and penalties when  $B_{zero}$  or  $M$  was fixed in the model at values between 1000 and 20 000 t and 0.05 and 0.60, respectively. The MPD fit is marked with an asterisk.**

|              | CPUE-2 | CPUE-1 | Photo-A | Trawl-A | Photo-LF | Trawl-LF2 | Trawl-LF1 | Comm-LF2 | Comm-LF1 | Maturity | Cod-end-C | Cod-end-R | Priors | Penalties |
|--------------|--------|--------|---------|---------|----------|-----------|-----------|----------|----------|----------|-----------|-----------|--------|-----------|
| <b>Bzero</b> |        |        |         |         |          |           |           |          |          |          |           |           |        |           |
| 1 000        | 0.4    | 0.0    | 3.0     | 0.0     | 0.0      | 0.0       | 0.0       | 2.8      | 6.0      | 0.0      | 3.7       | 1.1       | 22.3   | 0.0       |
| 2 000        | 0.1    | 0.0    | 0.5     | 0.2     | 5.7      | 6.0       | 0.1       | 0.2      | 2.6      | 0.0      | 1.5       | 0.5       | 5.0    | 0.0       |
| 3 000        | 0.0    | 0.0    | 0.2     | 0.3     | 7.1      | 7.5       | 0.1       | 0.2      | 1.6      | 0.0      | 0.9       | 0.3       | 1.6    | 0.0       |
| 4 000        | 0.0    | 0.1    | 0.1     | 0.3     | 7.9      | 8.4       | 0.1       | 0.1      | 1.0      | 0.0      | 0.6       | 0.2       | 0.6    | 0.0       |
| 4 663*       | 0.0    | 0.1    | 0.0     | 0.3     | 8.2      | 8.6       | 0.2       | 0.0      | 0.9      | 0.0      | 0.5       | 0.1       | 0.2    | 0.0       |
| 5 000        | 0.0    | 0.1    | 0.0     | 0.3     | 8.2      | 8.4       | 0.2       | 0.4      | 0.8      | 0.0      | 0.5       | 0.2       | 0.1    | 0.0       |
| 6 000        | 0.0    | 0.1    | 0.0     | 0.4     | 8.4      | 8.6       | 0.2       | 0.3      | 0.7      | 0.0      | 0.6       | 0.2       | 0.0    | 0.0       |
| 7 000        | 0.0    | 0.1    | 0.0     | 0.4     | 8.6      | 9.0       | 0.1       | 0.2      | 0.5      | 0.0      | 0.5       | 0.2       | 0.2    | 0.0       |
| 8 000        | 0.0    | 0.1    | 0.0     | 0.4     | 8.8      | 9.2       | 0.1       | 0.1      | 0.4      | 0.0      | 0.3       | 0.1       | 0.5    | 0.0       |
| 9 000        | 0.0    | 0.1    | 0.0     | 0.4     | 8.9      | 9.3       | 0.1       | 0.1      | 0.3      | 0.0      | 0.3       | 0.1       | 0.8    | 0.0       |
| 10 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.0      | 9.4       | 0.1       | 0.1      | 0.3      | 0.0      | 0.3       | 0.1       | 1.1    | 0.0       |
| 11 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.1      | 9.5       | 0.1       | 0.1      | 0.2      | 0.0      | 0.2       | 0.1       | 1.5    | 0.0       |
| 12 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.2      | 9.6       | 0.1       | 0.2      | 0.2      | 0.0      | 0.1       | 0.1       | 1.8    | 0.0       |
| 13 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.3      | 9.6       | 0.1       | 0.2      | 0.1      | 0.0      | 0.1       | 0.0       | 2.2    | 0.0       |
| 14 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.3      | 9.7       | 0.1       | 0.2      | 0.1      | 0.0      | 0.1       | 0.0       | 2.5    | 0.0       |
| 15 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.3      | 9.7       | 0.1       | 0.2      | 0.1      | 0.0      | 0.1       | 0.0       | 2.9    | 0.0       |
| 16 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.4      | 9.7       | 0.1       | 0.2      | 0.1      | 0.0      | 0.0       | 0.0       | 3.3    | 0.0       |
| 17 000       | 0.0    | 0.1    | 0.0     | 0.4     | 9.4      | 9.8       | 0.1       | 0.2      | 0.0      | 0.0      | 0.0       | 0.0       | 3.6    | 0.0       |
| 18 000       | 0.0    | 0.1    | 0.1     | 0.4     | 9.4      | 9.8       | 0.1       | 0.2      | 0.0      | 0.0      | 0.0       | 0.0       | 4.0    | 0.0       |
| 19 000       | 0.0    | 0.1    | 0.1     | 0.4     | 9.5      | 9.8       | 0.1       | 0.2      | 0.0      | 0.0      | 0.0       | 0.0       | 4.3    | 0.0       |
| 20 000       | 0.0    | 0.1    | 0.1     | 0.4     | 9.5      | 9.8       | 0.1       | 0.2      | 0.0      | 0.0      | 0.0       | 0.0       | 4.7    | 0.0       |
| <b>M</b>     |        |        |         |         |          |           |           |          |          |          |           |           |        |           |
| 0.050        | 2.3    | 2.7    | 21.8    | 0.3     | 171.4    | 725.0     | 164.8     | 203.6    | 343.5    | 0.0      | 0.0       | 0.0       | 64.3   | 7.5       |
| 0.075        | 2.0    | 2.3    | 21.2    | 0.2     | 104.8    | 360.1     | 85.5      | 41.5     | 188.7    | 0.0      | 3.2       | 12.1      | 47.1   | 2.4       |
| 0.100        | 1.6    | 1.6    | 18.6    | 0.1     | 66.1     | 193.9     | 47.3      | 0.0      | 105.3    | 0.0      | 3.3       | 24.2      | 34.4   | 0.2       |
| 0.125        | 1.2    | 0.9    | 15.9    | 0.0     | 45.9     | 107.6     | 26.3      | 5.1      | 58.9     | 0.0      | 4.2       | 33.6      | 27.7   | 0.2       |
| 0.150        | 0.6    | 0.3    | 6.3     | 0.0     | 38.3     | 69.5      | 15.8      | 21.0     | 34.8     | 0.0      | 3.9       | 39.1      | 24.8   | 0.1       |
| 0.175        | 0.2    | 0.0    | 2.1     | 0.1     | 39.3     | 55.6      | 11.2      | 33.1     | 22.4     | 0.0      | 2.8       | 41.5      | 12.5   | 0.0       |
| 0.200        | 0.0    | 0.0    | 0.6     | 0.3     | 41.4     | 50.1      | 8.8       | 42.4     | 14.5     | 0.0      | 2.1       | 42.8      | 1.6    | 0.0       |
| 0.213*       | 0.0    | 0.1    | 0.3     | 0.4     | 39.3     | 43.6      | 7.4       | 51.4     | 10.6     | 0.0      | 3.9       | 44.8      | 0.0    | 0.0       |
| 0.225        | 0.0    | 0.1    | 0.2     | 0.4     | 34.3     | 34.2      | 5.7       | 64.6     | 7.2      | 0.0      | 7.7       | 47.9      | 2.2    | 0.0       |
| 0.250        | 0.1    | 0.1    | 0.1     | 0.3     | 23.3     | 16.6      | 2.7       | 99.8     | 2.2      | 0.0      | 18.7      | 56.0      | 10.5   | 0.0       |
| 0.275        | 0.2    | 0.1    | 0.0     | 0.3     | 16.1     | 6.5       | 1.1       | 137.7    | 0.0      | 0.0      | 30.3      | 63.6      | 22.3   | 0.1       |
| 0.300        | 0.4    | 0.1    | 0.0     | 0.2     | 11.3     | 1.4       | 0.4       | 173.7    | 0.0      | 0.0      | 44.0      | 72.0      | 37.5   | 0.2       |
| 0.325        | 0.6    | 0.2    | 0.0     | 0.2     | 8.8      | 1.5       | 0.5       | 207.6    | 2.1      | 0.0      | 56.9      | 79.2      | 57.7   | 0.7       |
| 0.350        | 1.0    | 0.4    | 0.1     | 0.2     | 11.4     | 2.4       | 1.8       | 210.9    | 3.3      | 0.0      | 66.4      | 87.4      | 106.8  | 4.2       |
| 0.375        | 1.3    | 0.7    | 0.0     | 0.2     | 10.8     | 0.0       | 1.6       | 233.2    | 5.4      | 0.0      | 81.5      | 103.6     | 132.1  | 7.6       |
| 0.400        | 1.6    | 0.8    | 0.2     | 0.2     | 4.3      | 7.9       | 0.3       | 329.3    | 14.6     | 0.0      | 102.4     | 108.8     | 98.6   | 2.9       |
| 0.425        | 2.2    | 1.2    | 0.6     | 0.2     | 3.3      | 14.0      | 0.0       | 374.8    | 21.5     | 0.0      | 112.6     | 113.9     | 113.9  | 4.8       |
| 0.450        | 2.8    | 1.6    | 0.8     | 0.3     | 3.1      | 20.7      | 0.8       | 408.7    | 27.6     | 0.0      | 127.5     | 122.2     | 131.8  | 6.8       |
| 0.475        | 3.4    | 2.1    | 1.0     | 0.5     | 2.9      | 27.5      | 1.8       | 439.1    | 33.6     | 0.0      | 143.6     | 131.7     | 150.5  | 9.2       |
| 0.500        | 4.0    | 2.6    | 1.2     | 0.6     | 2.7      | 34.9      | 2.9       | 464.2    | 39.7     | 0.0      | 163.4     | 142.5     | 169.1  | 11.9      |
| 0.525        | 4.4    | 2.9    | 1.2     | 0.7     | 2.8      | 43.5      | 4.9       | 477.5    | 45.5     | 0.0      | 196.5     | 157.9     | 181.7  | 13.4      |
| 0.550        | 3.6    | 2.1    | 1.4     | 0.7     | 0.0      | 51.5      | 7.4       | 415.2    | 36.6     | 0.0      | 316.3     | 188.8     | 173.3  | 12.2      |
| 0.575        | 4.1    | 2.5    | 2.1     | 0.8     | 1.9      | 59.3      | 8.9       | 424.5    | 37.3     | 0.0      | 341.9     | 200.9     | 196.1  | 14.5      |
| 0.600        | 4.7    | 3.0    | 2.3     | 1.0     | 3.9      | 66.0      | 9.6       | 446.3    | 43.8     | 0.0      | 363.8     | 219.1     | 209.1  | 16.7      |

Deepwater species are typically difficult to assess, at least in part because estimates of absolute abundance and biomass are so difficult to obtain. For scampi, the development of a quantitative photographic approach provides a rare opportunity to compare model trajectories of total, recruited, or mature (spawning) biomass with independent estimate of absolute biomass. Cryer et al. (2003) derived estimates of the total biomass of visible scampi and suggested these could be used as minimum estimates of absolute biomass (because some scampi might be hidden from view in their burrows) (Figure 36, Table 12). Fully quantitative comparisons have not been made, but Cryer et al.'s (2003) estimates of minimum biomass are about 12–25% (mean 16%) of the spawning stock biomass trajectory in the MPD fit (less if the mean or median of the posteriors is used). This estimate of the “visible proportion” is probably slightly biased high because the minimum biomass estimates include all scampi (not just spawning stock), but most visible animals are relatively large and likely to be mature. This seems a plausible proportion of the biomass to be visible to surveying during daylight when trawl catch rates are highest and, presumably, emergence from burrows is greatest.

**Table 12 (after Cryer et al. 2003):** Estimates of the (total) biomass of visible scampi within strata 302, 303, 402, and 403 between 1998 and 2003 made using a mean average weight of 35.4 g. These estimates are probably close to estimates of “minimum biomass”. Scampi “not in burrows” were defined as those for which the telson was not obscured by a burrow. The specified c.v.s are underestimates because they do not include variance associated with conversions from observed cheliped length to individual weight.

|      | All visible scampi |           | Scampi not in burrows |           |
|------|--------------------|-----------|-----------------------|-----------|
|      | Biomass (t)        | Min. c.v. | Biomass (t)           | Min. c.v. |
| 1998 | 988                | 22.3      | 393                   | 45.8      |
| 2000 | 644                | 18.2      | 287                   | 25.4      |
| 2001 | 435                | 26.3      | 71                    | 53.5      |
| 2002 | 591                | 21.3      | 85                    | 61.6      |
| 2003 | 509                | 21.1      | 62                    | 40.9      |



**Figure 36 (after Cryer et al. 2003):** Estimated abundance ( $\pm$  one standard error) of visible scampi in strata 302, 303, 402, and 403, 1998 to 2003. Closed symbols indicate all visible scampi, open symbols include only those scampi completely out of their burrows.

The estimated abundance of visible scampi (Figure 36) declined much more markedly between 1998 and 2003 than did the estimated abundance of burrows or overall biomass (from burrow counts and their average size). This is consistent with the decline in commercial CPUE and research trawl catch rates between 1998 and 2003 and with the proposition that variation in catchability between years affects trawl catch rates and makes them poor candidates as indices of relative biomass, at least in the short-to-medium term.

We think the model is a reasonable representation of scampi dynamics in the Bay of Plenty, but we suggest several modifications and improvements for future projects. Some were discussed at the March 2004 meeting of the Shellfish Fishery Assessment Working Group. The two different approaches to including information on absolute biomass should be particularly pursued because this is where the model seems to be least informed.

- Further consideration of means of fitting selectivity ogives to codend selectivity data and, perhaps, the length frequency distribution of visible scampi (because fishing gear selectivity is probably a combination of emergence behaviour and gear selectivity).
- Further consideration of means of including photographic estimates of minimum absolute recruited biomass in the model (although developing a suitable likelihood will not be simple).
- Further consideration of means of permitting variable catchability in the model, by sex and/or between years.
- Further trials of means of fitting growth parameters within the model, with or without tag and aquarium data (some trial fits indicate that there is insufficient information for the model to converge without increment-at-length data).
- Development of a means of fitting N-based process error (e.g., for multinomial and binomial error structures) for each data set within the model.
- Fitting to a tag-based estimate of absolute abundance or biomass (using data from the 1995 growth experiment) within the model.

## 5. ACKNOWLEDGMENTS

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## 6. REFERENCES

- Annala, J.H.; Sullivan, K.J.; O'Brien, C.J.; Smith, N.W.McL.; Grayling, S.M. (comps.) (2003). Report from the Fishery Assessment Plenary, May 2003: stock assessments and yield estimates. 616 p. (Unpublished report held in NIWA library, Wellington.)
- Bull, B.; Dunn, A. (2002). Catch-at-age: User manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. NIWA. (Unpublished report held in NIWA library, Wellington.)
- Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H. (2004). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.06-2004/09/26. NIWA Technical Report 126. 261 p.
- Charnov, E. L.; Berrigan, D.; Shine, R. (1993). The  $M/k$  ratio is the same for fish and reptiles. *American Naturalist* 142: 707-711.
- Cryer, M.; Coburn, R. (2000). Scampi assessment for 1999. *New Zealand Fisheries Assessment Report 2000/7*. 60 p.

- Cryer, M.; Hartill, B.; Drury, J.; Armiger, H.J.; Smith, M.D.; Middleton, C.J. (2003). Indices of relative abundance for scampi, *Metanephrops challengeri*, based on photographic surveys in QMA 1 (1998–2003) and QMA 2 (2003). Final Research Report for Project SCI2002/01 (Objectives 1–3). 18 p. (Unpublished report held by Ministry of Fisheries, Wellington.)
- Cryer, M.; Oliver, M. (2001). Estimating age and growth in New Zealand scampi, *Metanephrops challengeri*. Final Research Report for Ministry of Fisheries Project SCI9802 (Objective 2).
- Cryer, M.; Stotter, D. R. (1997). Trawling and tagging of scampi off the Alderman Islands, western Bay of Plenty, September 1995 (KAH9511). *New Zealand Fisheries Data Report* 84. 26 p.
- Cryer, M.; Stotter, D. R. (1999). Movements and growth rates of scampi inferred from tagging, Aldermen Islands, western Bay of Plenty. *NIWA Technical Report* 49. 35 p.
- Francis, R.I.C.C. (1988). Maximum likelihood estimation of growth and growth variability from tagging data. *New Zealand Journal of Marine and Freshwater Research* 22: 43–51.
- Hartill, B.; Cryer, M. (2000). A review of the adequacy of current observer coverage and practices for scampi. Final Research Report for Ministry of Fisheries Research Project MOF1999/04J. 46 p. (Unpublished report held by Ministry of Fisheries, Wellington.)
- Hartill, B.; Cryer, M. (2004). Unstandardised scampi CPUE indices update for scampi 1988–2003. Final Research Report for Ministry of Fisheries Research Project SCI2001/02, Obj. 2. 35 p. (Unpublished report held by Ministry of Fisheries, Wellington.)
- Hartill, B.; Cryer, M.; MacDiarmid, A.D. (in press). Reducing bycatch in scampi trawl fisheries. *New Zealand Fisheries Assessment Report* 2005/xx. 59 p.
- I.C.E.S. (2000). Report of the study group on life histories of *Nephrops*, Reykjavik, Iceland. May 2000. *I.C.E.S. CM 2000:G, Living Resources Committee*. 184 p.
- Ihaka, R.; Gentleman, R. (1996). R: A language for data analysis and graphics. *Journal of Computation and Graphical Statistics* 5: 299–314.
- Pauly, D. 1980: On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil International pour L'exploration de la Mer* 39: 175–192.
- Ricker, W.E. 1975: Computation and interpretation of biological statistics of fish populations. *Bulletin* 191, Department of the Environment, Fisheries and Marine Service, Ottawa, Canada. 382 p.
- Smith, B.J. (2004). Bayesian Output Analysis Program (BOA) Version 1.1 User Manual. Unpublished manuscript available at <http://www.public-health.uiowa.edu>. University of Iowa. 39 p.
- Wear R.G. (1976). Studies on the larval development of *Metanephrops challengeri* (Balss, 1914) (Decapoda, Nephropidae). *Crustaceana* 30: 113–122.

## Appendix 1: Multinomial error structure and effective sample sizes for proportions-at-length.

After some problems with zero observations using our previous lognormal error structure, a multinomial error structure was assumed for catch-at-length and proportions-at-length data. Nominal and effective sample sizes for the multinomial were estimated using a two-step process. The first stage derived nominal sample sizes by assuming the relationship between the observed proportions,  $E_i$ , and estimated c.v.s,  $c_i$  (from the NIWA catch-at-age software), followed that for a multinomial distribution with unknown sample size  $N_j$ . The nominal sample size was estimated using a robust non-linear least squares fit of  $\log(c_i) \sim \log(P_i)$  for each catch-at-length or proportions-at-length data set (Figures A1 a, b, and c). The second stage estimated the effective sample size,  $N'$ , by adding additional process error,  $N_{PE}$  to the nominal sample size, where,

$$N' = 1 / \left( \frac{1}{N} + \frac{1}{N_{PE}} \right)$$

This "N-based" process error cannot be estimated within a CASAL model, but an initial MPD model fit can be used to estimate the additional process error by solving the following equation for  $N_{PE}$ ,

$$n = \sum_j \frac{(O_{ij} - E_{ij})^2}{E_{ij}(1 - E_{ij}) \left( \frac{1}{N_j} + \frac{1}{N_{pe}} \right)}$$

where  $n$  is the number of multinomial cells,  $O_{ij}$  is the observed proportions for length class  $i$  in year  $j$ ,  $E_{ij}$  are the expected proportions,  $N_j$  is the nominal sample size estimated in (a) above, and  $N_{PE}$  is the associated process error for that class of observations.

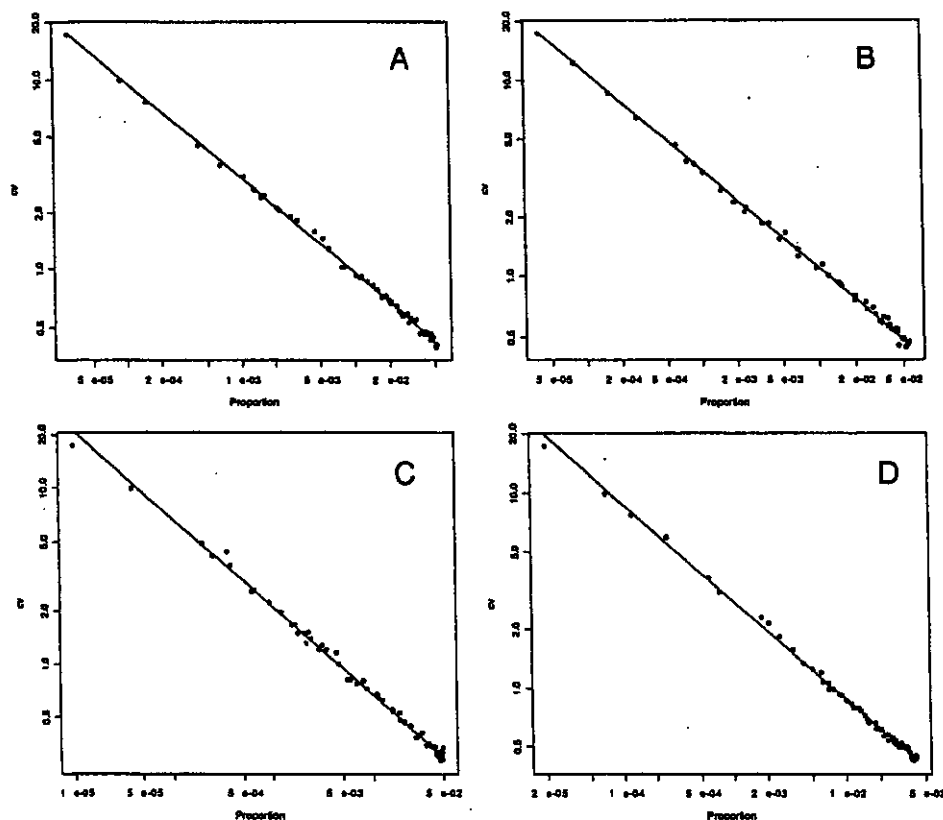


Figure A1a: Multinomial fits of precision on proportion for length frequency distributions estimated from burrow size in 1998 (A), 2000 (B), 2002 (C), and 2003 (D).



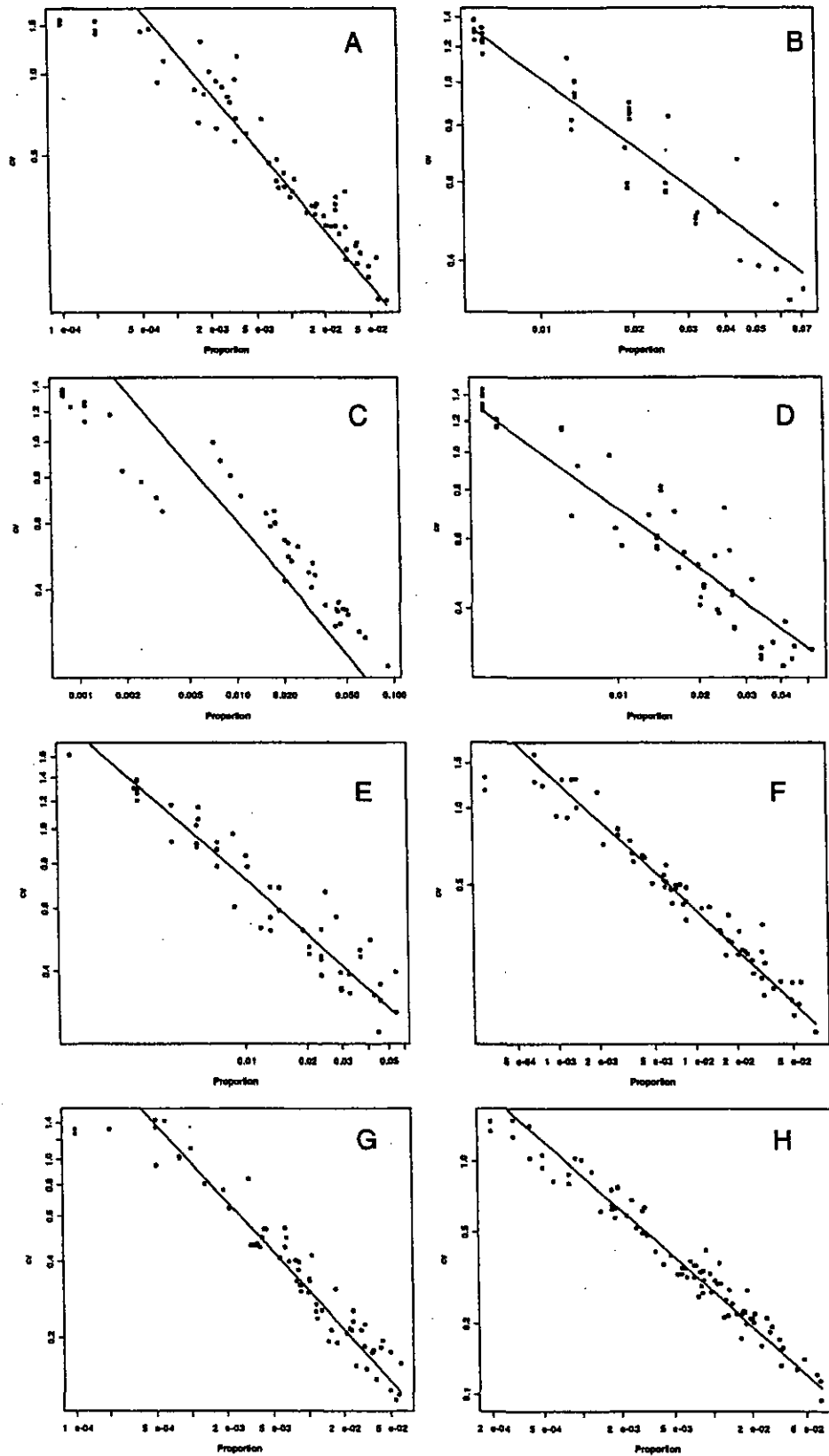


Figure A1b: Multinomial fits of precision on proportion for observer length frequency distributions from 1991-92 step 1 (A), 1992-93 step 1 (B), 1995-96 step 1 (C), and 2001-02 step 1 (D), 1991-92 step 2 (E), 1996-97 step 2 (F), 1998-99 step 2 (G), and 1999-2000 step 2 (H). Not shown is 1990-91 step 2.

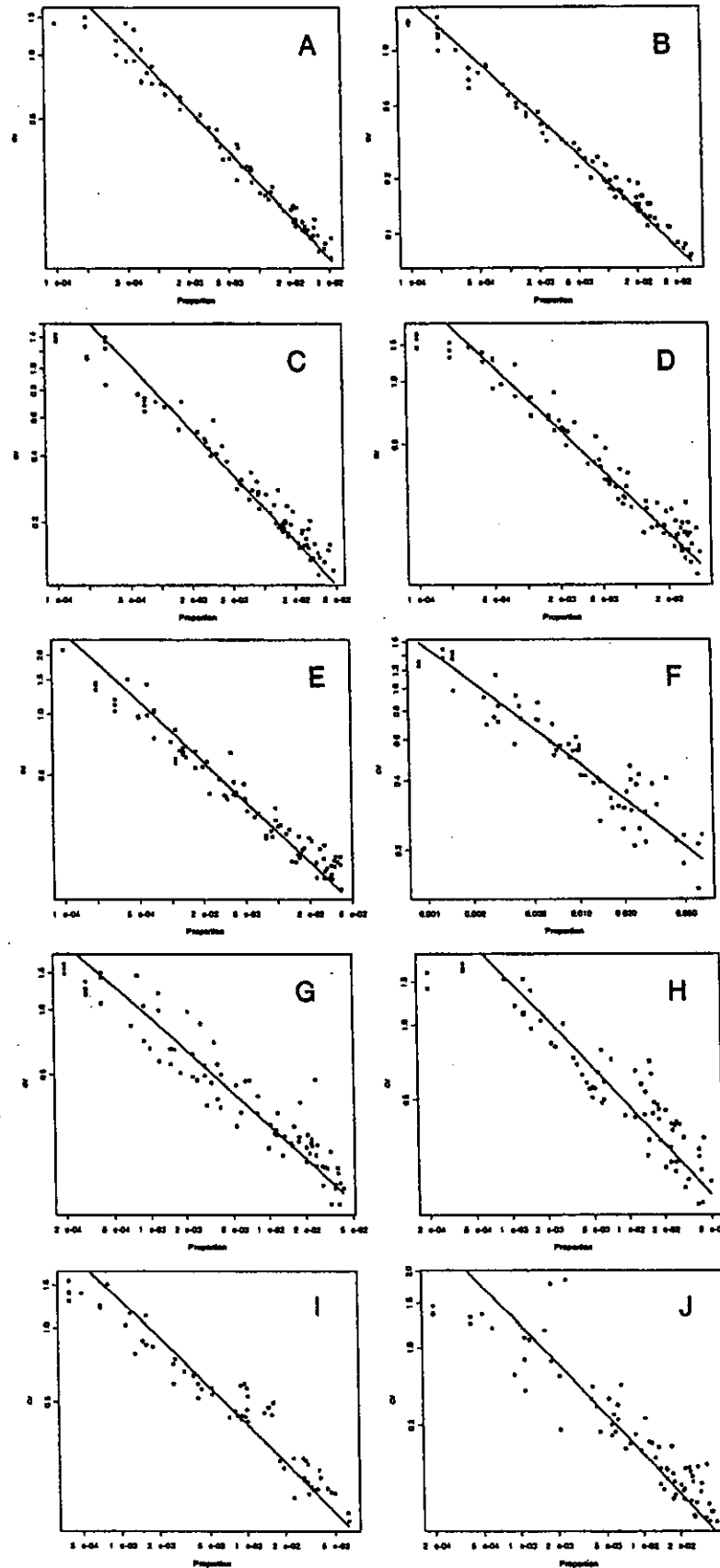
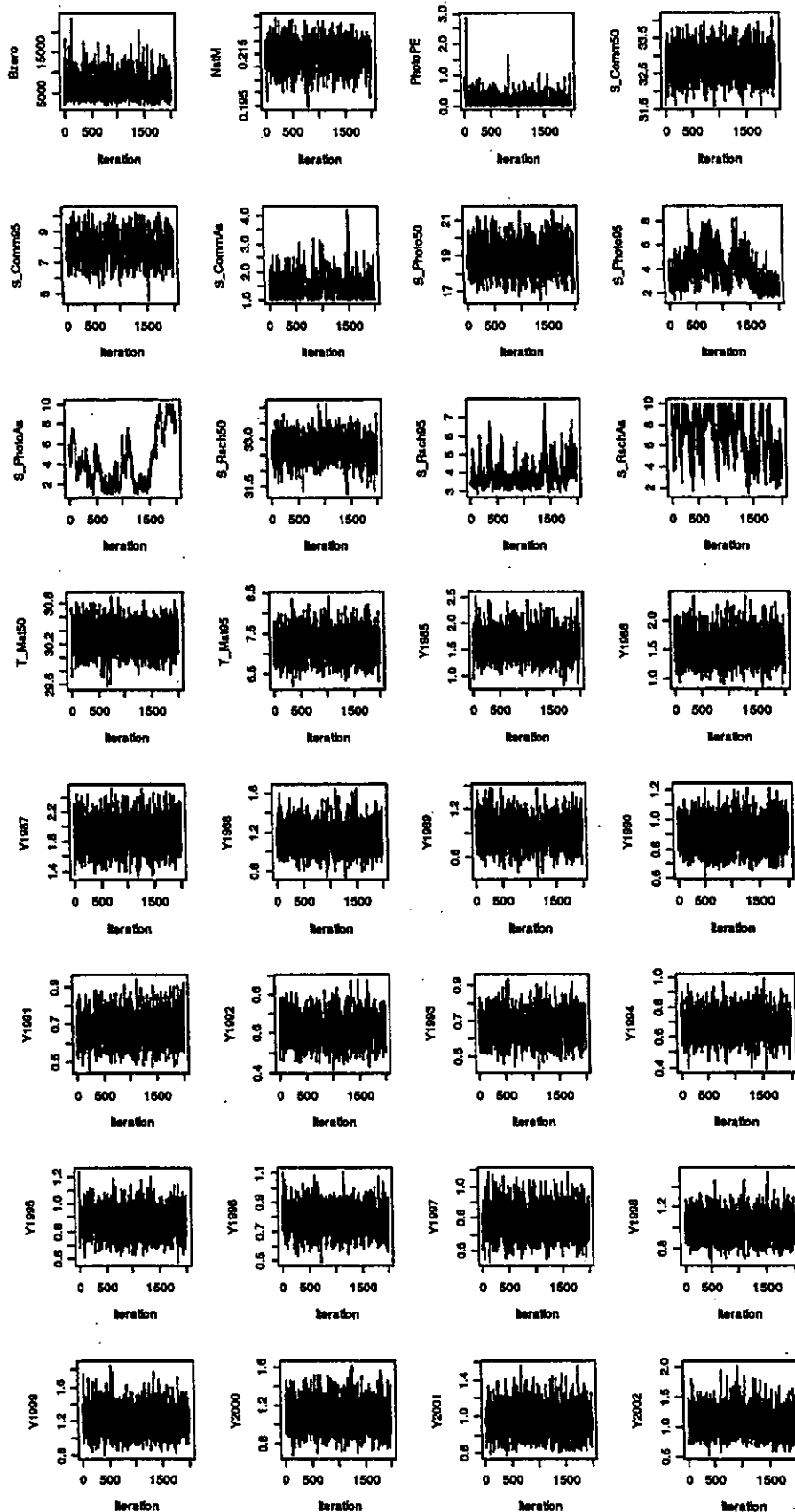


Figure A1c: Multinomial fits of precision on proportion for research length frequency distributions from 1995-96 step 1 (A), 1996-97 step 1 (B), 1992-93 step 2 (C), 1993-94 step 2 (D), 1994-95 step 2 (E), 1995-96 step 2 (F), 1997-98 step 2 (G), 1999-2000 step 2 (H), 2000-01 step 2 (I), and 2001-02 step 2 (J).

**Appendix 2: MCMC diagnostics for the base model.**



**Figure A2a: MCMC chains for estimated parameters in the base model. One million iterations (excluding a burn-in of 250 000 iterations) thinned systematically to 2000 samples.**

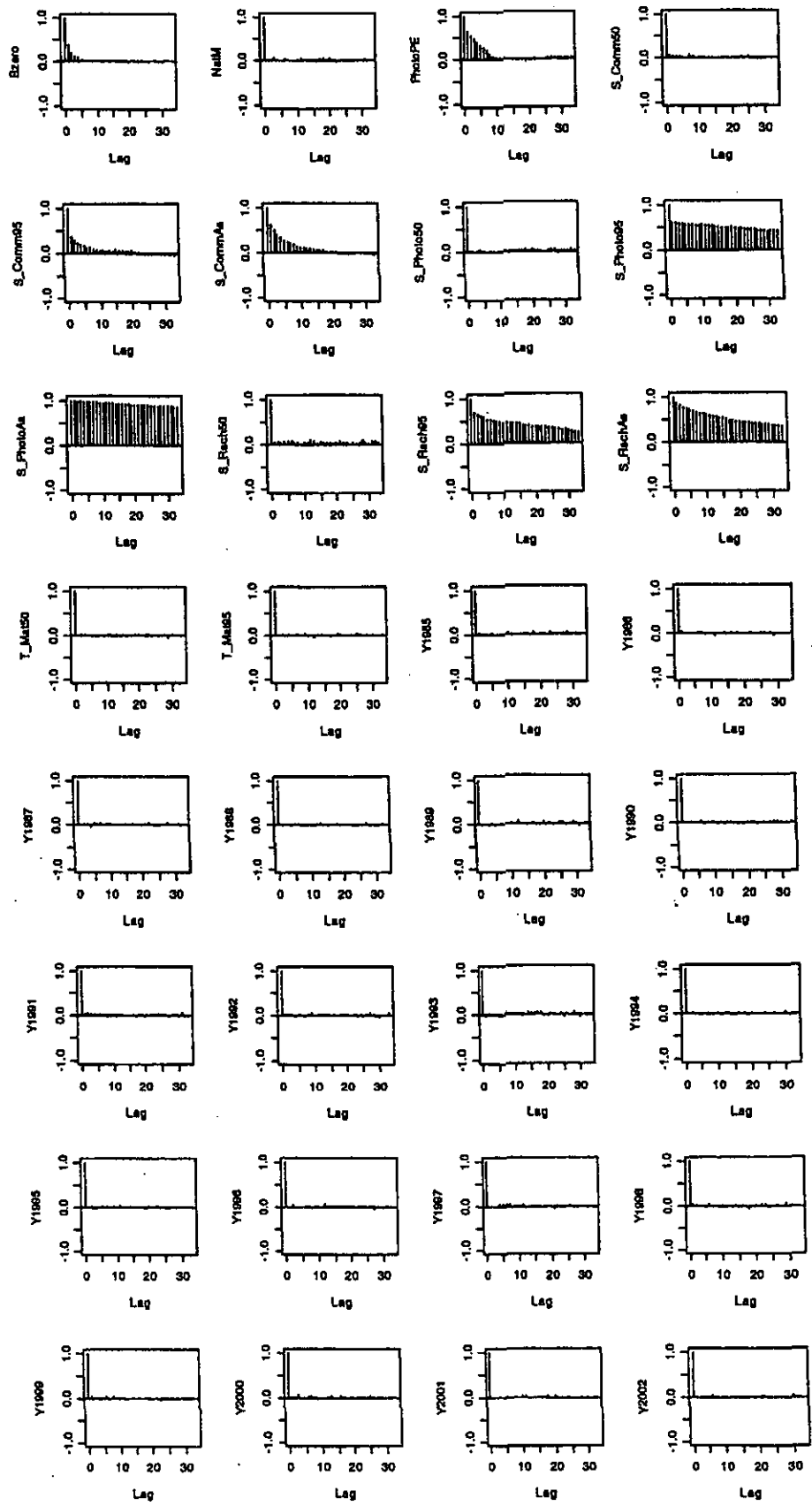


Figure A2b: Autocorrelation coefficients in MCMC chains for estimated parameters in the base model.

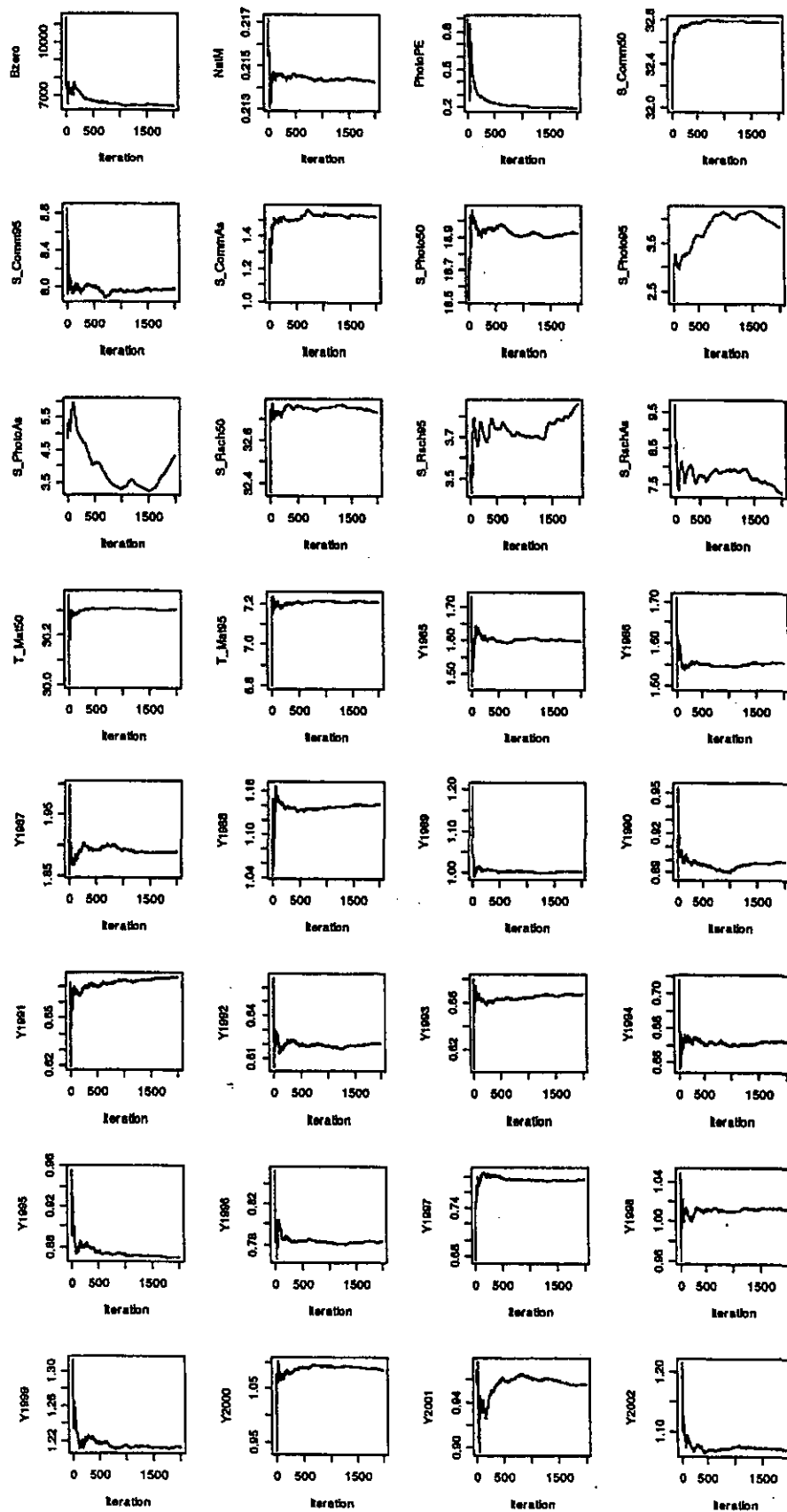


Figure A2c: Running means in MCMC chains for estimated parameters in the base model. One million iterations (excluding a burn-in of 250 000 iterations) thinned systematically to 2000 samples.

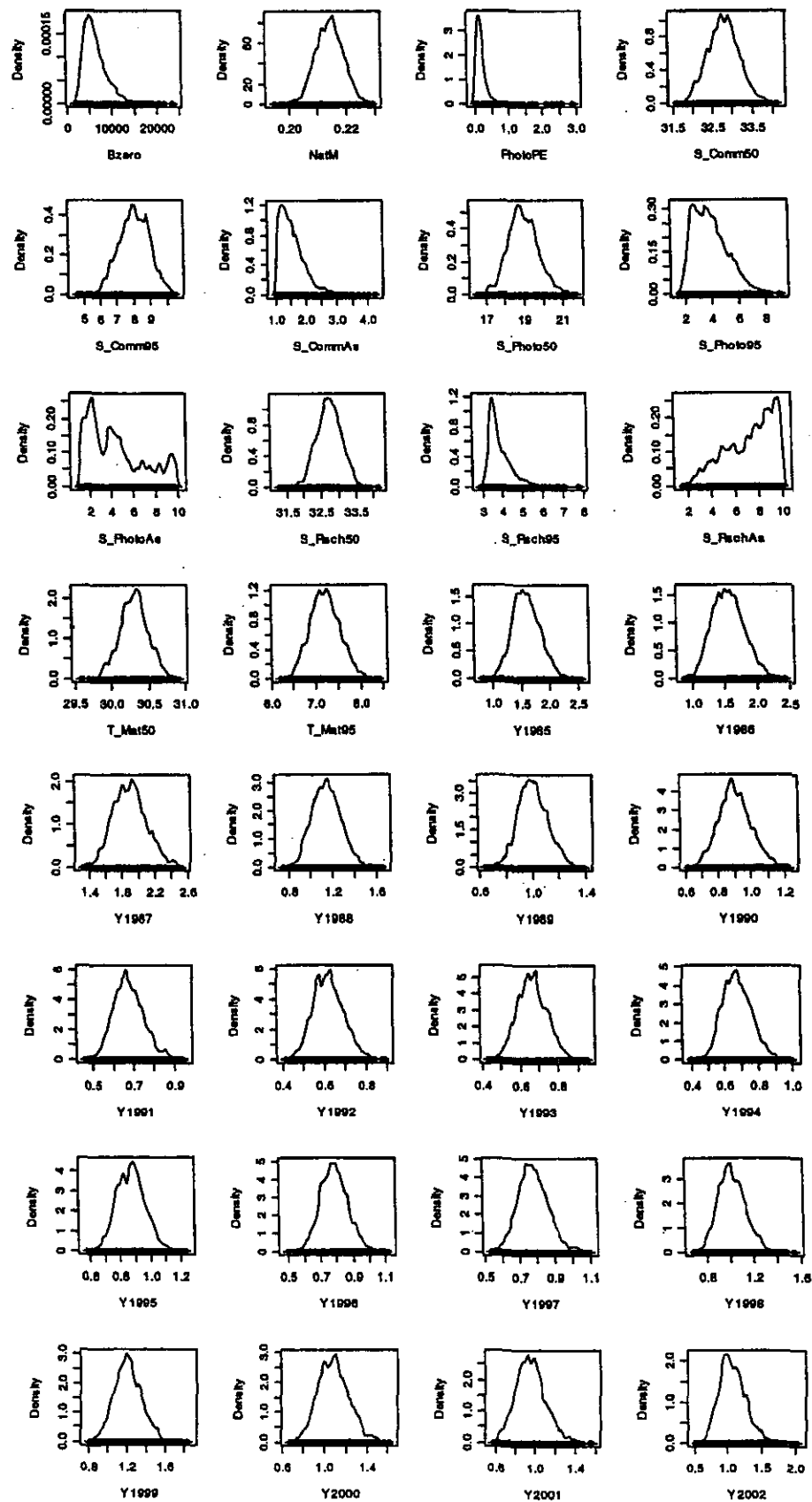


Figure A2d: MCMC estimates of posterior distributions for estimated parameters in the base model. One million iterations (excluding a burn-in of 250 000 iterations) thinned systematically to 2000 samples.

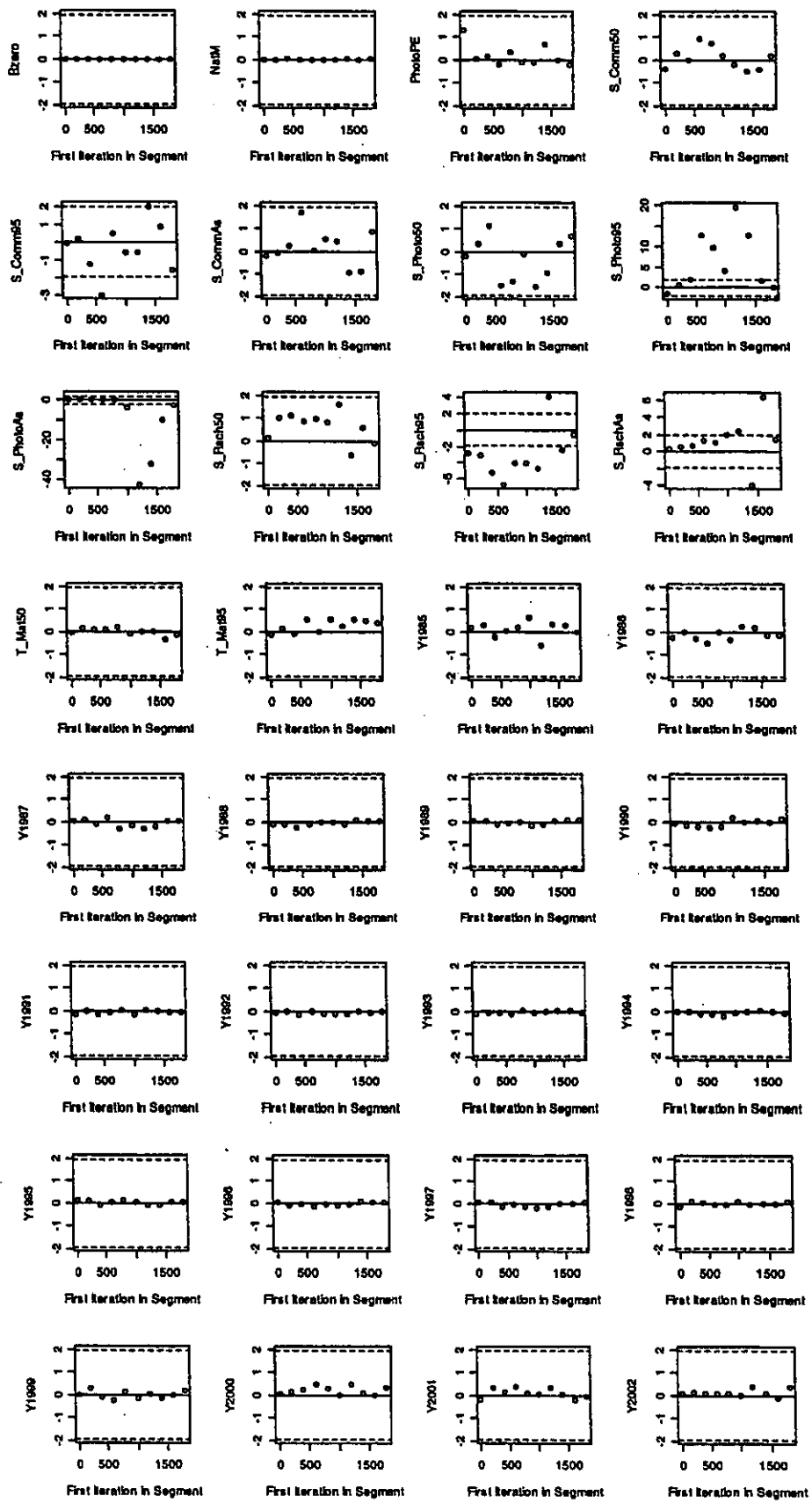


Figure A2e: Geweke convergence diagnostics for MCMC chains for estimated parameters in the base model. One million iterations (excluding a burn-in of 250 000 iterations) thinned systematically to 2000 samples.

