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Assessment of the SNA 8 stock for the 2004–05 fishing year

New Zealand Fisheries Assessment Report 2013/28

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EXECUTIVE SUMMARY

Davies, N.M.; McKenzie, J.R.; Gilbert, D.J. (2005). Assessment of the SNA 8 stock for the 2004–05 fishing year.

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The SNA 8 stock was assessed for the 2004–05 fishing year using an updated and revised population model. New data inputs to the model since the previous assessment in 2004 include: mean length-at-age, pair trawl catch length frequencies measured at sea, recreational catch length frequencies, and single trawl and pair trawl catch-at-age in the 1970s. Data updated since the 2004 assessment were: catch weights for the commercial fishery in 2004 (i.e. 2003–04; for convenience fishing years are referred to by the January year); single trawl and pair trawl catch-at-age estimates 2004; a revised time series of single trawl standardised CPUE time series 1996–2004. The single trawl CPUE was revised by excluding zero catch records and including only vessels that caught a high proportion of the catch. The indices showed a shallow decreasing trend from 1996 to 2001 followed by a general increase to 2004.

The data series to which the assessment model was fitted included: absolute biomass and population length composition derived from tag-recapture programmes in 1990 and 2002; CPUE time series for pair trawl 1974–91 and single trawl 1996–2004; catch-at-age estimates for pair trawl 1974 to 2004 (not all years), and single trawl 1974 to 1976, and 1991 to 2004; research trawl survey recruitment indices for 1984 to 1997 year classes (excluding 1990 and 1995), boat ramp samples of recreational catch length frequency in 1991, 1994, 1996, and 2000, and pair trawl at-sea catch length frequency in 1986.

Structural developments made to the model used for the 2004 assessment included: applying fishing mortality via length-specific selectivity ogives; estimating single trawl and pair trawl selectivity-at-length; and annual variability in individual growth rate. For the updated assessment these developments were extended. The series of boat ramp samples of recreational catch length frequency facilitated the estimation of a stepwise change in the recreational selectivity-at-length that takes account of the regulated change in minimum legal size for that fishery in 1994. The single trawl and pair trawl catch-at-age data from the 1970s facilitated the estimation of natural mortality. Observed mean length-at-age from the 1970s was considerably lower than in the recent data (1989–2004). Consequently, time-varying mean length-at-age was assumed, with slow growth from 1931 to 1979, average growth from 1980 to 1988, and rapid, variable growth from 1989 to 2004. The statistical assumptions made to resolve conflicts between observation types were examined by testing the sensitivity of the model to the relative weight of the tag-recapture absolute abundance estimates. Sensitivity to the assumed historical commercial catch was tested using an option with a non-equilibrium initial population starting in 1974 (option: Y1974), and sensitivity to historical annual recreational catch was tested with recent catches of either 300 t or 600 t (options: R300 and R600, respectively).

A consistently good MPD fit was obtained over the full range of observations, with the exception of a part of the tag-recapture population length composition in 2002 and the recreational boat ramp length frequency samples. The tag-recapture estimate of population length composition in 2002 for lengths over 55 cm appeared to conflict with other data. Model options assigning high relative weight to this part of the observed population length distribution produced worse fits to the single trawl CPUE, which indicates increases in recent biomass. Given this conflict and the level of uncertainty of the over 55 cm component of the tag-recapture estimate, the Snapper Working Group considered it reasonable to assign lower weight to this observation. The fit to the boat ramp length frequency samples was poor for the small length class intervals (25–31 cm) in some years. This appeared to be independent of the step-wise change in the selectivity-at-length, and may reflect high process error for this fishery (e.g. annual changes in selectivity).

It is unlikely that the Bayesian posterior distribution estimate of unfished equilibrium biomass (B_0) for any single option captures the full uncertainty of this parameter for the following reasons. Firstly, the credibility intervals are sensitive to the assumptions made regarding historical catches as indicated by the Y1974 and R600 model options. Secondly, instead of estimating natural mortality (M) as an independent parameter, the marginal posterior distributions for all the models were calculated under a constant value for natural mortality equivalent to that estimated from the MPD fit. This was done to address a technical problem with the Bayesian estimation procedure that is recommended to be resolved for future assessments. Thirdly, the model biomass must remain above zero in the mid 1980s while also maintaining a fit to the low absolute abundance estimates from the later tagging programmes. It is therefore constrained above and below, and hence the credibility intervals for B_0 for each option are narrow. An indication of the "true" uncertainty in B_0 is given by the range estimated over all options.

In contrast, MPD estimates of B_{04} were relatively insensitive to the assumptions tested, and were within a relatively narrow range of 9.6 to 11.5 kt, with B_{04}/B_0 having a range of 8.7% to 9.8%. For the two options selected by the Snapper Working Group, R300 and R600, B_{04}/B_0 was 9.5% and 9.8% respectively, and the 90% credibility intervals ranged between 7.8% and 12.5% of B_0.

Under all the model options and future commercial catch scenarios (500–1500 t) the biomass is predicted in stochastic model projections to increase on average. The rate of increase is considerably lower for the options for which a constant exploitation rate for the recreational fishery is assumed. Similarly, projections were less optimistic for the option assuming higher historical recreational catch. Under the current TACC, the best performing was the R300 option under constant recreational catch, where the probability of achieving 20%B_0 by 2025 is almost 50%. For all the model options the rate of increase is substantially improved with a reduction in the TACC, but this is strongly offset by increases in recreational catch where a constant exploitation rate is assumed for that fishery.

This report presents the findings as of 2007, and not at the current time of the report's publication. No updated information has been added to the assessment, and none of the interpretations have been revised since 2007.

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1. INTRODUCTION

1.1 Overview

This report presents the 2005 assessment of the west coast snapper stock, SNA 8, summarised by Sullivan et al. (2005). This work was carried out under Specific Objective 3 of the Ministry of Fisheries Project SNA2004/01: To update the assessment of SNA 8.

1.2 Description of the fishery

The SNA 8 fishery has been described by Sullivan (1985), Paul & Sullivan (1988), Davies (1997, 1999) and Davies et al. (1999). The trawl fishery developed from a small fleet operating from sheltered harbours with annual landings not exceeding 1000 t until the 1950s, when larger Auckland-based trawlers entered the fleet. Landings from the trawl fishery gradually increased and, together with the introduction of foreign vessels during the 1960s, were exceeding 2000 t per year by 1973 (Table 1). During the 1970s there was a rapid increase in landings to over 3000 t as a result of the transfer of trawl fishing effort from the east to the west coast, and the introduction of pair trawling in 1973. It is estimated that total landings from a combination of pair trawling and Japanese fishing operations increased to a peak of about 7600 t in 1976. After the establishment of the Exclusive Economic Zone (EEZ) in 1978, foreign fishing was excluded from SNA 8. Landings from the pair trawl fishery declined to about 3000 t by 1980. Annual landings continued to decline to about 1800 t in 1985–86.

With the implementation of the Quota Management System in 1986–87, commercial catches from SNA 8 were constrained by a total allowable commercial catch (TACC) of 1330 t. In 1986–87 landings were only 900 t, but they have been very close to the TACC since then (Table 2). Since 1989 there has been a steady decline in the proportion of total landings derived from pair trawling with a shift in emphasis to single trawling. In the 2003–04 fishing year single trawl vessels accounted for 79% of total landings. There has been a shift to single trawling since the 1980s in response to market demands for higher quality snapper, necessitating shorter tows and more careful fish handling practices that maintain the value of the catch.

Historically, the west coast snapper fishery has been seasonal, with most of the annual catch occurring during the spring and summer when fish aggregate for spawning. This pattern has not altered markedly in recent years.

2. REVIEW OF THE FISHERY

2.1 TACC

The TACC for SNA 8 was set at 1330 t in 1986–87 to permit stock rebuilding and increased to 1594 t by 1990 as a result of decisions made by the Quota Appeal Authority (Table 2). From 1 October 1992 the TACC was reduced from 1594 t to 1500 t and has not been changed since.

Landings in SNA 8 were less than the TACC in 1986–87 but have increased to closely match and exceed the TACC in recent years (Table 2). The consistent overrun since 1997–98 may be related to the low deemed value of SNA 8 fish relative to other snapper stocks.

2.2 Commercial landings

A change in the dominant fishing method in SNA 8 has occurred since 1989–90. Trawl landings make up on average 95% of total annual catch: single trawl has become more dominant in recent years and pair trawling less so.

Estimates of the total reported commercial landings for SNA 8 are available by calendar year from 1931 (see Table 1), with reported foreign catches for 1968–79 (Gilbert & Sullivan 1994).

2.2.1 Foreign fishing

Japanese catch records and observations by New Zealand naval vessels indicate that significant quantities of snapper were taken from New Zealand waters from the late 1950s until 1977. There are insufficient data to quantify the Japanese catches. However, trawl catches have been reported by area from 1967 to 1977, and longline catches from 1975 to 1977 (Table 3). The data series is incomplete, particularly for longline catches.

2.2.2 Illegal catch

No information is available to estimate illegal catch.

2.3 Non-commercial catch

2.3.1 Recreational fisheries

The 1987 National Marine Recreational Fishing Survey showed that snapper was the most important finfish species sought by recreational fishers. An estimate of recreational catch is available from the 1990 tagging programme for the whole of SNA 8 (239 t, Table 4). The results of telephone and diary surveys in the Central (1992–93) and North (1993–94) Fisheries Management Areas estimated recreational catch in SNA 8 to be between 300 and 420 t in 1994 (Teirney et al. 1997). This was later revised to be 238 t following a review of the regional and national surveys (Bradford 1999). The estimates of recreational catch in SNA 8 from the national surveys were 240 t in 1996 (Bradford 1998), 661 t in 2000 and 1133 t in 2001 (Table 4). The latter two surveys applied a different interview format, and the last survey had largely new diarists but used some parameter estimates from the 2000 telephone survey.

2.3.2 Maori fisheries

Snapper is an important species for Maori, but the annual catch is not known.

3. SNA 8 stock assessment information

3.1 Stock structure

No information that would alter the accepted stock boundaries of the west coast snapper stock (SNA 8) has become available since the 2004 assessment. SNA 8 is assumed to be separate from the other six snapper stocks with boundaries defined by the SNA 8 Quota Management Area (Mana

Island to North Cape). For the age-structured model, the SNA 8 stock was assumed to be discrete, i.e., no emigration or immigration of fish across stock boundaries.

Recapture sample length, age compositions, and movements of recaptured fish from the 2002 tagging programme have been reviewed (Walsh et al. 2006). There were some spatial differences in length and age composition between areas, and this was supported by the observation that movements of tagged fish were relatively localised (almost all movements were less than 50 n. miles within a season). Although differences in population length and age composition were evident at the northern and southern boundaries of SNA 8 relative to central areas (Figure 1), these differences were not attributed to large-scale mixing with adjacent snapper stocks (Walsh et al. 2006). These results support the assumption made of the SNA 8 population comprising a relatively discrete unit stock.

3.2 Biomass estimates

3.2.1 1990 tagging programme

An estimate of the absolute biomass of snapper recruited to the SNA 8 fishery is available from the results of a tag-recapture study in 1990. Details of the analysis, including corrections made for initial mortality and growth, have been described by Davies et al. (1999). The estimate of 9505 t was input into the 1999 and 2004 assessment models. The simulation estimates of precision were considered conservative (c.v. less than 0.1) and c.v.s of 0.18 and 0.3 have been assumed in the updated assessment presented here.

The tag-recapture estimates of absolute numbers in each of five length strata were projected over 1 cm length intervals by Davies et al. (2006). This is expressed as population proportions-at-length in Figure 2.

3.2.2 2002 tagging programme

A tag-recapture study was carried out in SNA 8 in 2002 and a description of the cryptic Passive Integrated Transponder (PIT) tag technology used is provided by McKenzie et al. (2006), and the estimator used to derive population parameters is described by Gilbert et al. (2005). The absolute biomass estimate was 10 442 t (c.v. 0.12). The population proportions-at-length are presented in Figure 2. Variances of the numbers-at-length were derived from the estimated Hessian matrix, and the c.v.s ranged from 0.24 at 25 cm, to a minimum of 0.06 at 35 cm, and 0.30 at 66 cm.

3.2.3 Catch-per-unit-effort (CPUE) pair trawl 1974–91

Vignaux (1993) presents a time series of pair trawl abundance indices from 1974 to 1991 that have been an input to SNA 8 assessment models in the past ten years. The time series indicates a rapid decline in catch rates from the mid 1970s to mid 1980s with increases occurring following the introduction of the Quota Management System in 1986.

3.2.4 Catch-per-unit-effort (CPUE) single trawl 1996–2003

The time series of trawl catch and effort data recorded on Ministry Catch Effort Landing Return (CELR) and Trawl Catch Effort Processing Return (TCEPR) begins in September 1989. Abundance indices for nine fishing years (1995–96 to 2003–04) were derived using this data. This updates the analysis carried out for the 2004 stock assessment with improved assumptions made regarding the core vessels included.

3.2.4.1 General linear model (GLM)

The model was described by Davies et al. (2006) for the 2004 assessment and only a brief outline follows. The standardised CPUE analysis used is adapted from Francis (1999).

A general linear model procedure (Equation 1) was used to derive standardised CPUE abundance indexes for SNA 8,

$$\log(CPUE_i) = \alpha + \sum_j Y_j I_{ij} + \sum_k A_k J_{ik} + PV_i + \varepsilon_i$$

where Y_j is the year coefficient in the jth year, A_k is the area coefficient in the kth area, P is the vessel attribute coefficient, V_i is the vessel attribute for the ith observation, and ε_i is the error on the ith observation. I_{ij} = 1 if observation i occurs in year j, and zero otherwise. J_{ik} = 1 if observation i occurs in area k, and zero otherwise. The coefficients Y and A in Equation 1 represent deviations from an arbitrary reference year (r) and area (s) (typically the first year and area in the respective series), therefore $Y_r = 0$ and $A_s = 0$.

The standardised regression procedures were then used to derive estimates ($\hat{Y}_j, \hat{A}_k, \hat{P}$) of the coefficients Y_j , A_k and P. The CPUE index was derived by exponentiating the year coefficient, $y_j = \exp(\hat{Y}_j)$.

The expected value of y_r, the reference year index, is always 1 and therefore the variance is 0. The variance on the other CPUE indices (Var(y_j)) represents the variation in the expected value of y_j relative to the expected value in the reference year (1). The variance estimates for each year index will alter depending upon the choice of reference year. In order to derive variance estimates for each year index independent of the others, it is necessary to convert the year indices to their canonical form (Francis 1999). The canonical variances reflect how well the GLM model fits the variation in the CPUE data. The GLM variances do not necessarily represent the true variability of the y_j as indices proportional to biomass, i.e., there may be changes in catchability between years that increase variability around a proportional relationship. The GLM variances will usually underestimate the "true" index variance (Francis 1999).

A problem with the GLM approach arises when zero values are present in the catch data. Although a zero catch per unit effort observation can be legitimate, zero is impossible in GLM log-space. Two options for dealing with zero values are either to remove them from the data, or to add a very small value to the observation to allow its inclusion. Both options may bias the CPUE index. Because there were relatively few zero values in the SNA 8 CPUE data where snapper was the target species, the approach taken was to remove these catch records from the analysis.

3.2.4.2 GLM fitting criteria

The following variables were fitted in the GLM models.

Year:	as fishing-year (October to September); categorical
Month:	January to December; categorical
Snapper target:	yes, no; categorical

Statistical area: 39, 40, 41, 42, 45, 46, 47; categorical
Vessel ID: categorical

All terms were first entered into the model, including all possible combinations of interaction terms, to estimate the degree of interaction between the year term and the other predictor variables.

A stepwise fitting procedure was then implemented; a GLM was run fitting first to the year parameter. Statistically significant main effects terms were then sequentially added into the model followed by statistically significant interaction terms not involving the year parameter. Predictor variables were accepted into the model only if they explained at least 0.5% additional deviance.

3.2.4.3 SNA 8 CPUE data

The TCEPR reporting forms require fishers to provide information on individual tows, whereas catch data recorded on CELR forms is amalgamated for each 24-hour period, i.e., total daily catch (in kilograms), total number of tows. Although most SNA 8 trawl skippers switched to the TCEPR forms after 1994, a significant proportion of SNA 8 CPUE data collected before 1994 exists on CELR forms. For the 2004 assessment, the unit of CPUE was modified to use an improved definition of fishing effort (Davies et al. 2006). Fishing effort was defined for each tow in terms of distance (nautical mile), i.e., duration × tow speed. Thus, CPUE was defined as kg n. mile^{-1}. This definition precluded using the CELR data and TCEPR data for the early part of the series (pre-1996).

Because of the relatively low number of observations in recent years it was considered reasonable to exclude recent pair trawl CPUE data from the updated analysis.

A grooming process was followed that resulted in the removal of "unsuitable" or sparse records from the complete data set (31 066 records). Based on the distributions of "tow-speed" (kt) and tow-duration, records were excluded if they contained fields with values that fell outside the tails of the distributions. CELR records were ignored, and TCEPR records prior to the 1995–96 fishing year are scant, and were therefore excluded. The paucity of records available relating to "year", "month" and "target" for statistical areas: 037, 043, 044, and 048 necessitated the removal of these statistical areas from the dataset. The fishing power of the single trawl fleet increased in the mid 1990s with the addition of new and larger vessels. To remove the potential for bias caused by differences between vessels over the time series, vessels that did not contribute appreciably to the fishery were excluded from the GLM. Vessels were retained that displayed continuity and longevity of fishing operations, and that accounted for a high proportion of catch and effort throughout 1996–2004. Two options for a vessel criterion were considered: retaining the top 12, or top 20 vessels. These criteria significantly reduced the incidences of zero catches. After grooming, 21 500 and 16 359 records remained for the top 20 or top 12 vessel options, respectively.

3.2.4.4 Results

The data used for the 2004 assessment was updated to 2003–04 and the GLM was undertaken using the same variables as in 2004. The data showed a decreasing trend in the proportion of zero catches. Various methods were attempted to include this information, such as adding a constant to the zero catches, or using a combined model where the probability of a zero catch was modelled as a binomial distribution and then the binomial year coefficients were multiplied by the lognormal year coefficients. The former approach resulted in unacceptable model diagnostics, and for the latter approach, the change to the abundance indices was relatively minor compared to those derived from using the positive catch data only. This confirmed the decision made by the Snapper Working Group to exclude zero catch data in the GLM.

The full GLM based on catch-per-distance-towed produced significant year interaction terms with target and statistical area predictor variables (Appendix 1), and although these explained less than 2% additional deviance, some caution applies. This effectively means that there is a different annual index at each level of the other predictor variables, e.g. each statistical area has a different abundance signal. It should be noted that the year index derived from the subsequent stepwise GLM (which did not include year interaction parameters) is effectively a data weighted average over all the other predictor variables.

No predictor variables were excluded from the model by the AIC stepwise regression procedure (Appendix 2). The year indices from the stepwise GLM for catch-per-distance-towed for both the top 12 and top 20 vessel options are shown in Figure 3. The indices showed a shallow decreasing trend from 1996 to 2001 followed by a general increase to 2004. These core vessel analyses were considered more appropriate than those used to generate the 2004 series. There was virtually no difference between the year indices based on the data from the top 20 or the top 12 vessels. The series based on the top 12 vessels was used. Canonical variance estimates were typically low (Davies & McKenzie 2001) with c.v.s generally less than 0.05 (Table 5).

3.3 Year class strength

3.3.1 Catch-at-age

3.3.1.1 1989–2004

Length frequency and otolith samples have been collected annually from single trawl and pair trawl landings in SNA 8 since the 1989 fishing year. Catch-at-age data were available for the following methods and years:

- pair trawl 1989, 1990, 2000–2004
- single trawl 1991–2004.

Details of sample sizes, proportion at length distributions in catches, and the distribution of length-at-age contained in the age-length keys were presented by Davies & Walsh (1995),Walsh et al. (1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004), and Walsh & Davies (2004).

The data input to the 2004 SNA 8 assessment was updated with the single trawl and pair trawl catch-at-age estimates for 2004 (Figure 4). Relatively strong recruitments are apparent for the 1996 and 1998 year classes, however, the 1999 and 2000 year classes appear to be of average strength (Walsh & Davies 2004). Fish in the aggregate age class (20+ years) are virtually absent.

A significant log-log transformed relationship was found using a functional regression between the c.v.s of trawl proportions at age and the proportion at age estimates for 1989 to 1996 (Davies 1997). This relationship was updated to include the most recent data and used to describe the observation error of the trawl proportions at age for the years where variance estimates were unavailable (1986 and 1987). Coefficients of variation for the years 1989 to 2004 were available.

3.3.1.2 Historical

For the 2004 assessment, catch-at-age estimates for the pair trawl fishery in 1975, 1976, and 1979 were input to the model (Table 6). With this information it was possible to obtain a model estimate of natural mortality (Davies et al. 2006). This development prompted a detailed examination of the length and age samples collected during the 1970s to add to these historical data and to potentially improve upon the natural mortality estimates for the updated assessment.

The sampling design used in the 1970s differed from that employed currently for SNA 8, with direct random sampling for age frequency. Generally a fixed number of fish were randomly sampled from each of a random selection of bins within each landing. An estimate of the landing catch-at-age was calculated by scaling up each bin sample frequency to the number of fish in each bin, and then scaling up to the number of bins in the landing. Annual catch-at-age was the mean of the seasonal estimates scaled to the landed weights in each season. This was to maintain consistency with the recent data having a seasonal distribution where little of the annual catch is taken from the winter months, which are not sampled. Seasons comprising a year were defined as spring to winter.

The protocol for ageing otolith samples from these landings differed from that used for the recent catch-at-age data. To determine the consistency between the series, a subset of samples from the historical data was aged using the current protocol. Samples from four pair trawl landings (392 otoliths) collected in winter 1974 were aged, and the readings compared with those obtained previously. For ages 1 to 10 years 17% of the readings altered, and for ages older than 10 years about 50% of the readings altered. Most often the differences were by one or two years with the majority of the original readings being lower. Despite this, the age distribution derived from the two readings showed similar patterns of year class strength (Figure 5).

Catch-at-age data were available for the following methods and years:

- pair trawl 1974–76, 1978–80; and
- single trawl 1974–76.

These estimates indicate that catches in the mid to late 1970s contained a high proportion of fish over 19 years of age (Figure 6).

3.3.2 Recruitment indices

Research trawl survey estimates of recruitment indices are available for the year classes 1984 to 1997, excluding the 1990 and 1995 year classes (Table 7, taken from Morrison & Parkinson 2001). This updates the indices input to the previous assessment with the additional indices for the 1996 and 1997 year classes.

3.4 Mean length-at-age

Davies et al. (2003) described mean length-at-age data for SNA 8 (1989 to 1998), and showed inter-annual variation in growth with consequent deviations in annual mean length-at-age from that predicted from von Bertalanffy growth functions used in SNA 8 assessments prior to 2004 (Table 8). In most years, estimates were lower than the predicted values, apart from 1988–89, i.e. the year from which data was used to estimate the published von Bertalanffy function (McKenzie et al. 1992). Given the importance of this parameter for model estimates of population biomass and catch weights, the available data for observed mean length-at-age was used in the model for the 2004 SNA 8 stock assessment. This data has been updated to include 2003–04, and supplemented with observations from length and age samples collected from 1974 to 1980 (see Section 3.3.1.2).

The length and age sampling design used in single and pair trawl landings from 1974 to1980 has been described. The analysis of mean length-at-age is described in Appendix 3. Data from single trawl and pair trawl landings collected during the spring and summer months were used for calculating mean length-at-age for consistency with data collected in the recent years.

An approach was developed to take account of inadequate sampling of the older age classes (Davies et al. 2003). There is scant data for age classes 11 years and older, and therefore growth of these age classes has probably not been well observed. For the years having observations, the mean length-at-age of fish aged 3 to 10 years was calculated directly from the length-at-age data. The pooled 1989–

2004 length-at-age data was used to derive a von Bertalanffy growth curve, from which mean length-at-age was predicted for ages 11 to 19 years. Similarly, the pooled data from 1975–79 was used for predictions in that period. For the respective periods, the mean length-at-age of the 20+ age class in the component years was derived directly from the pooled length-at-age data for that age class.

The mean length-at-age for 1989–2003 has been described by Davies et al. (2006). The mean von Bertalanffy growth function estimates for the two periods 1975–79 and 1989–2004 are presented in Table 8, and a comparison of the mean size-at-age expressed in terms of weight-at-age is presented in Figure 7. Growth rates are relatively similar for ages 3 to 6 years; however there is large divergence for the older age classes. Slower growth is clearly apparent from samples collected in the 1970s relative to the recent period, as indicated by the lower L_{inf} estimate: 53.98 compared to 68.16. Observations from 2004, although similar to those from the 1970s for ages 3 to 7 years, are higher for age 8 to 10 years, and the observations for older age classes are consistent with the mean von Bertalanffy function for the recent period.

It may be speculated that the slower growth rates for older age classes observed in the 1970s may be attributable to either density-dependence (Rose et al. 2001) or temperature related effects (Davies et al. 2002). The 2004 assessment model of SNA 8 predicted high stock biomass until the 1960s, when it was around 73% of unfished biomass (Davies et al. 2006). In contrast, estimates of biomass in the 1980s were considerably lower, at around 8% of unfished biomass. This large difference would cause faster recent growth if growth were density-dependent. Similarly, cooler sea surface temperatures around New Zealand pre-1970 would have produced slower growth rates if growth were temperature dependent. It was therefore reasonable to assume a growth rate for the period before 1975 that was slower than in recent years. For periods without observations (1931–1974, 1977–78 and 1981–88), mean length-at-age was assumed. A constant mean length-at-age vector for ages 3–19 years was assumed for the years 1931–1974 and 1977–78 that was derived from the von Bertalanffy curve fitted to observations from the period 1975–79. The mean observed length-at-age 20+ was assumed. A constant vector, being the mean of the von Bertalanffy functions for the two periods 1975–79 and 1989–2004, was assumed for the period 1981–88. The mean of the observed mean length-at-age 20+ for the two periods was assumed.

3.5 Method-specific selectivity-at-length

Estimates of method-specific selectivity patterns for SNA 8 were available from the 1990 and 2002 tag-recapture studies and were applied in the 2004 assessment (Davies et al. 2006). Selectivity-at-length parameters for the pair and single trawl methods were estimated independently in the analysis of the 2002 tag-recapture programme, using a double-normal function (Gilbert et al. 2005). The 1990 estimate of single trawl selectivity indicates higher selectivity for small fish (less than 30 cm, Figure 8). These estimates provide independent information on method-specific selectivity that has been considered in specifying the priors for Bayesian estimation of selectivity parameters (see Section 4.2.5.3).

3.6 Catch-at-length

3.6.1 Recreational boat ramp samples

Recreational length frequency data are available from four boat ramp surveys carried out in 1991, 1994, 1996 and 2000 that include ramps servicing the SNA 8 recreational fishery. The first survey, conducted almost entirely in the first six months of 1991, aimed to collect baseline information on recreational fisheries operating in the Auckland Fisheries Management Area. The survey conducted in the first six months of 1994, examined the validity of mean fish weights reported by diarists, as part of a regional telephone/diary survey. The first national telephone diary survey was conducted in 1996, and a national boat ramp survey took place which estimated mean fish weight for the recreational fishery. A similar survey was conducted in 1999–2000. Most interviewing has taken place at boat ramps close to population centres, predominantly around Auckland. These catch-at-length data were input to the updated assessment model, to allow the estimation of recreational selectivity-at-length.

The method-specific, temporal and spatial composition of the recreational fishery was examined in evaluating the representativeness of boat ramp length frequencies. Boyd et al. (2004) summarised the recreational snapper catch from SNA 8 using diary data from the 1999–2000 survey, indicating that 80% was taken by trailer boats and dinghies, and around 8% from shore-based methods. Although from only a single year, this information suggested that boat ramp samples are reasonably representative of recreational catches. Hartill et al. (1998) present the balanced design employed for sampling boat ramps with respect to weekdays and weekends. However, the surveys were not conducted throughout the year in some years (1991 and 1994). For the annual surveys the temporal distribution of samples was compared to the catch reported in the diary surveys, revealing similar seasonality with around 90% of the catch taken from December to April (B. Hartill, NIWA pers. comm.). Recreational fishers operate either inside or outside of the large west coast harbours. Interviewers recorded the fishing location associated with each sample that enabled a comparison of the location-specific length frequencies. A clear difference was evident with smaller fish taken inside the harbours that was consistent in all four surveys. Diary data collected concurrently was used to define the proportion of annual catch taken from each location. This was compared to the boat ramp proportions, and found to be inconsistent within and between years (B. Hartill, NIWA pers. comm.). Therefore, the location-specific boat ramp length frequencies were scaled by the diarist proportions of location-specific annual catch to produce annual estimates of the recreational catch length frequency (Figure 9). No diary survey was conducted in 1991, so the spatial distribution of the catch determined from the diary survey in 1994 was assumed for that year. The effects of the increase in the minimum legal size (MLS) from 25 cm to 27 cm for the recreational fishery in October 1994 is evident in the length frequency distributions.

3.6.2 At-sea pair trawl catch samples

Past regulation changes in SNA 8 are likely to have affected selectivity patterns of the trawl fishery. In 1986, a zone excluding trawlers was imposed for the waters within one nautical mile of the coast for a substantial part of the coastline. In the same year regulations were implemented for an increase in the cod-end mesh size from 100 mm to 125 mm. An at-sea catch sampling survey was carried out at the time to collect pair trawl length frequencies from catches using both cod-end mesh sizes (authors' unpublished data). As expected the larger mesh size reduced the relative selectivity-at-length for snapper in the small length intervals (under 35 cm, Figure 10). Although derived from a small number of trawl shots, this information was used to examine the implications of the regulation changes on the relative selectivity-at-length of the trawl methods, with a view to estimating stepwise changes in selectivities. The mean catch-at-length distribution (Figure 10) provided an observation of the catch composition for the pair trawl method in 1986.

3.7 Biological parameters

The biological parameters used in this and previous assessments are given in Table 8 (Gilbert & Sullivan 1994, Davies 1997, 1999, Davies & McKenzie 2001, Davies et al. 2006). The previous value for natural mortality of 0.075 was used to specify a prior distribution for this parameter even though it had been estimated from essentially the 1970s catch-at-age data used here (see Section 4.2.5.3). The previous von Bertalanffy parameters are given for comparison (see Section 3.4).

4. Stock assessment model

4.1 Changes to the SNA 8 assessment model

Biomass and yield were estimated using a revised and updated assessment based on an age-structured population model with length-specific fishing mortality, developed using the CASAL modelling framework (Bull et al. 2004). The model was fitted to two tag-recapture population estimates, a single trawl CPUE time series, trawl survey recruitment indices, catch-at-length and catch-at-age data. The updated model includes a number of new features advanced from the model used in the 2004 stock assessment, and these are outlined below.

4.1.1 New inputs to the model

In updating the 2004 SNA 8 assessment model to 2005, in addition to updating the existing observations input to the model, a range of revised and new observations were input including mean length-at-age, pair trawl catch length frequencies measured at sea, recreational catch length frequencies, and single trawl and pair trawl catch-at-age in the 1970s.

4.1.1.1 Updated observations

Observations from SNA 8 to which the assessment model is fitted were updated from that used in the 2004 assessment. Updated observations included:

- catch weights for the commercial fishery in 2003–04;
- single trawl and pair trawl catch-at-age estimates 2003–04;
- single trawl standardised CPUE time series 1996–2004.

4.1.1.2 Mean length-at-age

Section 3.4 above describes the available mean length-at-age data for SNA 8. Annual variability in mean weight-at-age in the recent time period (1989–2004) was high, with up to 35% difference between years for 8-year-old fish. Growth rates of age classes 6 years and older was considerably slower in the 1970s compared to the recent period. The model used annual mean length-at-age estimates with a constant average observation error (c.v. 0.08).

4.1.1.3 Pair trawl catch-at-length

Pair trawl catch-at-length frequencies measured at sea were input into the model with a view to estimating pre- and post-1986 selectivities.

4.1.1.4 Recreational catch-at-length

The 2004 assessment model assumed constant selectivity-at-age for the recreational method assuming an ogive equivalent to the 2002 tag-recapture estimate of single trawl selectivity-at-length (Davies et al. 2006). The boat ramp catch-at-length distributions for the recreational method were input into the model to allow the estimation of a stepwise change in selectivity corresponding to the change in MLS for the fishery in 1994.

4.1.1.5 Trawl catch-at-age 1974–80

The historical pair trawl catch-at-age data (from 1975, 1976, and 1979) was amended to include other years for which data was available and to add data from single trawl catches. This expanded the pair trawl series to cover the years 1974, 1975, 1976, 1978, 1979, and 1980, and added a single trawl series for the years 1974, 1975, and 1976. This improved upon the information available on the proportion of catches of fish in the age class 19 years and older.

4.2 Model description

The underlying model structure has been described by Davies et al. (2006) for the 2004 SNA 8 stock assessment, so only a brief outline follows. Details of the CASAL model formulations used are described by Bull et al. (2004). The model assumes a single stock with discrete age classes 3 to 20 years; the final age class is an aggregate for fish older than 19 years. Recruitment is defined as the number of 3 year-old fish entering the population each year, and no relationship exists between spawning stock and recruitment. A single sex population is assumed as growth in snapper is not sexually dimorphic and sex ratios are generally even (Paul 1976). Natural mortality (M) is assumed to be constant for all ages. Method- and length-specific fishing mortalities were calculated for four fishing methods (single trawl, pair trawl, longline and recreational) using the separability assumption (Fournier & Archibald 1982, Deriso et al. 1985, Methot 1990) for method-specific selectivity-at-length patterns and the reported catch weights. An instantaneous exploitation rate catch equation was used with a maximum annual total of 0.7.

Length-specific processes for fishing mortality with inter-annual variation in length-at-age were applied. The length distribution of three year-old fish may typically include fish less than the minimum legal size (MLS 25 cm), with the lower 95th percentile in some years being 23 cm. These fish comprise a negligible component of the population over all years, and, given the selection patterns estimated from the 2002 tag-recapture programme, are unlikely to be recruited to the trawl fisheries. In effect, the growth and selection parameters of the model produce a recruitment process that resembles knife-edge recruitment at age three years. Consequently, annual population biomass is defined as including fish in all age classes 3 y and older.

Three years old fish in SNA 8 are sexually mature (authors' unpublished data). Therefore, a maturity ogive was not included in the model, and all fish in the population are assumed to be sexually mature. However this assumption has no material effect because no spawner-recruit relationship was included in the model.

Population dynamics were modelled in discrete fishing year time steps from 1931 to 2004. It was assumed that at the beginning of the first fishing year, the population was in unexploited equilibrium with constant mean recruitment. This initial population estimate defined the maximum unfished, or "virgin", biomass, B_0. The following order for within-year transition processes was assumed: ageing, adding annual recruitment, reducing population numbers due to natural mortality and method-specific annual catches. The "current" estimates derived from the model relate to the population at the start of the 2005 fishing year.

Provision was made for under-reporting of the commercial catch (20% before 1987 and 10% since the QMS was introduced). Japanese longline catches from 1965 to 1977 were included in the commercial catch history, but because reports were unavailable for the period 1965 to 1974, an annual catch of 2000 t was assumed for this fishery.

For the 2004 stock assessment, the assumption regarding historical recreational catches was reviewed on the basis of available estimates. Estimates of 661 t in 2000 and 1133 t in 2001 were reported (Table 4) indicating that recreational catch may be higher than assumed previously, although the Snapper

Working Group believes that considerable uncertainty surrounds all of the recreational catch estimates. There was anecdotal information to support the implication of the surveys that recreational catch has increased since 1990. However, the nature of this increase was unclear. For the updated assessment it was decided to use two alternative recreational catch time series:

- $C_{rec,300}$, 1931–90 = 60 to 300 t linear increase; 1990–2004 = 300 t (constant)
- $C_{rec,600}$, 1931–90 = 120 to 600 t linear increase; 1990–2004 = 600 t (constant)

To examine population point estimates for the 2005 fishing year, the model was projected deterministically from 2004 to the start of 2005 by removing the reported commercial catches in 2004, assuming constant recreational catch ($C_{rec,300}$ or $C_{rec,600}$ depending upon the model), and assuming mean recruitment. For 2005, commercial catches were assumed to equal the TACC of 1500 t (plus 10% overrun) allocated proportional to the method-specific catches reported in 2004.

4.2.1 Model developments for an updated assessment

In updating the 2004 SNA 8 assessment, it was reasonable to adopt the main assumptions and specifications described by Davies et al. (2006). However, certain assumptions were reviewed in light of the new information input to the model. The updated model was developed with consultation with the Ministry of Fisheries Snapper Working Group. An outline of the main stages of this process follows to provide a background of the model used for the 2005 assessment.

To examine the effects of including new observations and parameter modifications to the model, a stepwise approach was followed. New observations were added to the model successively, beginning with updating the time series used in the 2004 assessment (catch-at-age, CPUE, catch-weights), and then adding the revised catch-at-age estimates for the 1970s, recreational catch-at-length (1990s to 2000), and at-sea pair trawl catch-at-length. Modifications were then made where possible given the new information available to estimate additional parameters. Examples include: increasing the maximum age class to 50 years consistent with catch-at-age observations collected in the 1970s, estimating stepwise changes in trawl method selectivity-at-length due to changes in cod-end mesh sizes, fitting the 2002 tag-recapture estimate as absolute numbers at length, and estimating stepwise changes in selectivity-at-length for the recreational method by fitting to the catch length frequencies collected at boat ramps. The vulnerability of 3-year-olds to recreational fishing was adjusted to account for the increase in 1994 in the recreational MLS (to 27 cm). These developments were assessed by diagnostic examination.

In attempting to include these new features within one base case model, problems were encountered estimating the recreational selectivity-at-length parameters and calculating Bayesian model estimates for natural mortality. The relative leverage of respective observations on model estimates was examined by: adjusting the relative weight of the data types, calculating a likelihood profile for mean recruitment, calculating the parameter correlations, and determining the MCMC acceptance rates for the various model options prepared during the stepwise model development. This examination revealed mean recruitment and natural mortality to be highly correlated, which may have contributed to poor MCMC performance when estimating natural mortality. Although it was thought that a high maximum age (50 years) might improve the estimation of natural mortality, it rendered the model computationally intensive to the extent that MCMC calculations became impractical. These considerations and other details of the model led the Snapper Working Group to agree upon a revised set of potential base case specifications. These could not be encapsulated in one single base case but were instead advanced as a set of alternative, equally plausible options. Certain other potential model options, were compared to the base model options and discarded from the assessment as being implausible or requiring unreasonable assumptions.

Other sensitivities to base model options were specified to test robustness to uncertainty in historical catches and statistical assumptions regarding the tag-recapture observation of absolute abundance.

Bayesian estimates were calculated, and presented to a Plenary meeting. It was determined at this meeting that the statistical assumption made under the base model options regarding the fit to the tag-recapture observations of absolute numbers at length assigned unduly high weight to these data. The assumption made under an alternative option was considered more reasonable, which involved fitting the tag-recapture observation as an absolute biomass index instead of absolute numbers at length. Also, lower relative weight was recommended for both the 1990 and 2002 tag-recapture observations. These recommendations were followed in specifying five model options finally used for the updated assessment and described in detail in Section 4.2.5.2 below. As before, there was no single base case model.

4.2.2 2005 assessment model specifications

The specifications and assumptions shared by all model options, some of which differ from the 2004 assessment model, are:

- stepwise changes in selectivity-at-length for the recreational method, pre-1994 (MLS 25 cm) and post-1994 (MLS 27 cm);
- left-hand limb of the recreational selectivity-at-length is assumed to be knife-edge at the MLS;
- recreational selectivity-at-length is maximum at the MLS;
- the fit to the boat ramp length frequencies (all years) is duplicated for both the pre-1994 and post-1994 recreational selectivity-at-length functions to ensure that the estimated right-hand limb parameters are the same;
- single trawl and pair trawl selectivity-at-length are time invariant, with left-hand limbs constrained to closely resemble those of the 2002 tag-recapture estimates;
- longline selectivity-at-length is constant (equal to 1.0);
- natural mortality is estimated at the MPD but fixed for the Bayesian posterior estimation;
- C_{rec} is either 300 t or 600 t;
- mean recruitment corresponds to the period 1971 to 2000, i.e. mean $YCS_{1971\text{-}2000} = 1.0$;
- observed mean weight-at-age is assumed for the years available: 1975–79 and 1989–2004;
- von Bertalanffy estimates of mean weight-at-age taken from the period 1975–79 were assumed constant for all years pre-1975;
- the average of the two von Bertalanffy estimates of mean weight-at-age for the periods 1975–79 and 1989–2004 were assumed constant for all years between 1980 and 1988;
- the mean observed weight at 20+ years is assumed for the 1975–79 and 1989–2004 periods respectively, with the mean value for 1975–79 assumed for the years pre-1975, and the average of both periods assumed for the years 1980–88.

4.2.3 Estimated parameters

The model parameters estimated were:

$\overline{R}$	mean annual recruitment of 3 year old fish;
r_t	annual recruitment indices of year class strength (YCS) for the 1971 to 2000 year classes (n = 30)
a_1, s_L, s_R	selectivity at length for double normal function; single trawl, pair trawl and recreational methods (n = 8, only the right-hand limbs of the recreational functions were estimated)
M	natural mortality.

Annual year class strengths were the product of the mean recruitment and YCS, hence, the year class strength of 3-year-old fish at the start of year t was $\overline{R} \times r_t$.

Mean recruitment directly determines initial population biomass in the unfished equilibrium state, B_0, given the assumed values for natural mortality and growth.

Four catchability coefficients were required for the model fit to the abundance indices of CPUE and recruitment, and these were derived analytically.

4.2.4 Model predictions

The model was used to predict variables:

$\hat{B}_t$	absolute stock biomass at the start of year *t*; includes all age classes 3 years or more;
$\hat{I}_{m,t}$	CPUE abundance index for fishing method *m* in year *t*; proportional to the mid-year population biomass vulnerable to fishing method *m*;
$\hat{p}_{m,t,a}$	proportion of catch-at-age *a* for fishing method *m* in year *t*;
$\hat{l}_{m,t,i}$	proportion of catch-at-length *i* for fishing method *m* in year *t*;
$\hat{L}_{t,i}$	proportion of fish at length *i* in the population in year *t*.

The model was also used to predict variables that related to biological reference points:

B_{MSY}	the level of equilibrium population biomass that supports the maximum sustainable yield given mean recruitment at the estimated $\overline{R}$ level;
MSY	the maximum sustainable yield.

4.2.5 Model fitting

The observations to which the model was fitted were:

1. Absolute biomass – derived from tag-recapture programmes in 1990 and 2002;
2. Population length composition – derived from tag-recapture programmes in 1990 and 2002;
3. CPUE – pair trawl time series 1974–91; single trawl time series 1996–2004;
4. Catch-at-age – pair trawl 1974, 1975, 1976, 1978, 1979, 1980, 1986, 1987, 1989, 1990, 2000 to 2004; single trawl 1974 to 1976, and 1991 to 2004;
5. Boat ramp samples of recreational length frequency in 1991, 1994, 1996, and 2000;
6. Pair trawl catch-at-length distributions for cod-end square mesh sizes 100 mm and 125 mm in 1986;
7. Research trawl survey recruitment indices: 1984 to 1997 year classes (excluding 1990 and 1995).

Research trawl survey indices of recruitment are available for year classes surveyed either in the 2+ or 3+ year classes (Morrison & Parkinson 2001). Differences in the catchability between these age classes are likely to be because of the performance and selectivity-at-length of the sampling gear used. Therefore, two separate datasets were fitted, one for each age class, with different catchability coefficients.

The random variables absolute biomass, population proportions-at-length and numbers-at-length, CPUE and research trawl survey recruitment indices were assumed to be log-normally distributed. The random variables catch-at-age, pair trawl and recreational catch-at-length, were assumed to be multinomially distributed.

4.2.5.1 Relative weighting of observation types

The relative weightings of the seven data types to which the model was fitted, were specified in the likelihood function by the observation and process error assumed. High assumed error assigns low relative weight. The individual likelihood terms making up the total objective function and the formulation for process error is described by Bull et al. (2004). The assumed error for each observation type is presented in Table 9.

For annual catch-at-age estimates, correlation between fish ages within a landing means that variability is higher than would be predicted by the sample size. We have therefore assumed multinomial variability with effective sample sizes that were 5% of the actual otolith sample sizes. For years where a single age-length key was applied to length frequency estimates from more than one fishing method, the effective sample size was divided by the number of fishing methods.

Observation error estimates of CPUE were available for pair trawl 1974–91 (Vignaux 1993) and for the single trawl 1996–2004 (Section 3.2.3 above). However, the canonical variances for the single trawl CPUE 1996–2004 were low (c.v. less than 0.05). For both CPUE time series, process error (i.e. increased sampling variance) was assumed (0.2) such that the total error term (c.v.) in the likelihood was in the range 0.20–0.30. This is generally consistent with the likely error for CPUE indices (Francis et al. 2001).

Tag-recapture estimates of observation error for absolute biomass and population length composition were available from the 2002 programme (Gilbert et al. 2005). A set of 12 parameters were estimated by the tag-recapture estimator, being the absolute population numbers in each of 12 length intervals, with the numbers at length for all other length intervals determined by interpolation. High weight was assigned to these 12 length intervals with relatively low weight assigned to those having interpolated values. Variances for the 1990 tag-recapture length composition estimates were considered less reliable, and observation error was assumed using the 2002 variances with ad hoc scaling (multiplying by 2). A variance estimate of the absolute biomass in 2002 was available (c.v. 0.12). No estimate was available from the 1990 tag-recapture study, and a variance was assumed that was higher than that of the 2002 estimate (c.v. 0.18). The sensitivity of the model to these assumptions was tested by increasing the observation error to a c.v. of 0.2 and 0.3 for 2002 and 1990 respectively (see Section 4.2.5.2 below). No process error was assumed for the tag-recapture estimates of population length composition (absolute numbers-at-length or proportions) or absolute biomass.

Observation error estimates for research trawl recruitment indices are available (Morrison & Parkinson 2001) and process error was added for these observations consistent with that used for the 2004 assessment (Table 9). Greater process error was assigned to the 3+ y indices because the survey samples fish of this size range less consistently.

Observation error estimates were not available for either the boat ramp samples of recreational catch length frequency or the at-sea samples of pair trawl catch length frequency for alternative cod-end mesh sizes. Given the large numbers of landings in the annual boat ramp surveys (number of fish 1951 to 3317) a relatively high constant effective sample size was assumed (Table 9). However the model was unable to consistently fit these data well. Therefore, relatively high process error was assigned in using these observations as representations of annual recreational catch length frequency. Similarly, low effective sample size was assigned to the at-sea pair trawl length frequency observations because of the low number of samples and limited geographical range of the survey (Table 9). This assumption was regarded as adequate for down-weighting this observation, and no process error was added.

In assigning the appropriate relative weight to the various observation types, the standard deviations of the standardised residuals were examined. Values near 1.0 were considered consistent with the statistical assumptions and assumed variances.

4.2.5.2 Base model specifications

An indication of the uncertainty relating to structural and statistical assumptions made in the model is provided by the following options. All options shared the specifications given in Section 4.2.2 above. Their differences are defined as follows:

Tag02num – fits to the 2002 tag-recapture estimates of absolute numbers-at-length; C_{rec} = 300 t;

Y1974 – as for Tag02num, with initial non-equilibrium population numbers at age estimated in 1974; natural mortality assumed equal to Tag02num estimate; C_{rec} = 300 t;

Tag02bio - fits to the 2002 tag-recapture estimates of absolute biomass and population proportions-at-length, cv[$B_{tag,2002}$] = 0.12; C_{rec} = 300 t;

R300 - fits to the 2002 tag-recapture estimates of absolute biomass and population proportions-at-length, cv[$B_{tag,2002}$] = 0.2; cv[$B_{tag,1990}$] = 0.3; C_{rec} = 300 t;

R600 - fits to the 2002 tag-recapture estimates of absolute biomass and population proportions-at-length, cv[$B_{tag,2002}$] = 0.2; cv[$B_{tag,1990}$] = 0.3; C_{rec} = 600 t;

The mode of the Bayesian posterior distribution (MPD) was obtained to give point estimates of parameters from each option.

The Tag02num option assigns relatively high weight to the 2002 absolute abundance estimate compared to the Tag02bio, R300 and R600 options. The Y1974[1] option makes fewer assumptions regarding historical catches, such as the level of unreported Japanese longline catch between 1965 and 1974. The R300 and R600 options test the model sensitivity to historical recreational catch weights.

The Snapper Working Group determined that although Bayesian estimates (the marginals of the posterior distributions) were calculated for all model options, only those for R300 and R600 should be used for the assessment and projections.

4.2.5.3 Assumed priors

Specifications for the priors assumed for the parameters are given in Table 10. For all model options, uniform-log priors were assumed for $\bar{R}$ and the catchability coefficients, and uniform priors for YCSs. The uniform priors for the YCSs were chosen for the technical reason that it is convenient to allow all the YCS parameters to be estimated freely and then to scale them to a mean value of 1.0 (the Haist parameterisation, Bull et al. 2004).

For single trawl and pair trawl selectivity-at-length, informed priors were specified using independent estimates from the 1990 and 2002 tag-recapture programmes. Normal distributions were assumed. The design and implementation of the 2002 programme is considered to be superior to the 1990 programme. Therefore, the mean values for the priors were taken directly from the 2002 programme estimates of single trawl and pair trawl selectivity-at-length. Variances were determined from the estimates from both programmes and a range defined by the relative differences between the two sets of estimates. Few catch-at-length observations were available of fish close to or below the MLS, from which estimates of the left-hand limb could be derived. The variances for the left-hand limb parameters were therefore set low, making the prior highly informed.

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[1] The Y1974 estimate of natural mortality was shown to be highly confounded with the initial start population numbers at age. To overcome this the Y1974 model was rerun using the Tag02num estimate of natural mortality.

For recreational selectivity-at-length, priors were specified on the basis of previous independent estimates from tag-recapture studies of east and west coast snapper populations. The mean of the prior for the right hand limb was set lower than that of the single trawl parameter to give comparatively higher selection of small fish by the recreational method. A relatively broad prior was assumed for this parameter (c.v. 0.5). The lack of information available for estimating the length at maximum selection and the left-hand limbs necessitated fixing maximum selection at the MLS (different pre-1994 and post-1994 values) and the left-hand limb as a knife-edge slope.

For natural mortality, the mean of the prior was assumed equal to the value assumed in previous SNA 8 assessments (0.075 y^{-1}). A relatively broad log-normal distribution was assumed (c.v. 0.5).

4.2.6 Monte Carlo Markov chain (MCMC) procedure

Full Bayesian estimates of the parameters were calculated for each of the model options listed in Section 4.2.5.2 above by calculating the marginal posterior distributions. CASAL uses the Metropolis algorithm for estimating the posterior distribution, and a full description of its application is provided by Bull et al. (2004). The starting point of the Markov chain was the point estimate (MPD) and a burn in of 100 000 iterations were discarded before selecting every 1000th sample from 4 million iterations. The resulting 4000 samples from the estimated posterior distribution were used to generate predictions, and statistics that were examined for signs of lack of convergence using a range of diagnostics. These statistics included the likelihood objective function value, B_0, selected YCS and biomass estimates. For each statistic, plots were examined of the traces, running means, autocorrelation and Geweke (1992) convergence plots and the Raftery & Lewis (1992) convergence statistics. These were calculated using the Bayesian Output Analysis (BOA) software in the statistics package, R.

As mentioned above (Section 4.2.1), the close correlation between M and mean recruitment resulted in poor MCMC performance. Consequently, M was assumed fixed at the MPD estimate for each model option when undertaking the MCMC calculations. This assumption prevented calculation of Bayesian estimates for M.

4.2.7 Projections and performance indicators

Projections were carried out only for the R300 and R600 model options.

For each draw of parameters from the posterior sample, the model was projected from the start of the 2005 fishing year to 2025, with stochastic recruitment (by randomly resampling the year class strengths in each draw with replacement). It was assumed that future growth was constant at the rate observed in recent years (1989–2004). Future mean weight-at-age was assumed from the von Bertalanffy function derived for this period.

It was assumed that future commercial catches were allocated between fishing methods in proportion to the method-specific catches in 2003–04, with a 10% overrun in the catch. A range of alternative future commercial catch regimes were considered, including constant catch at the current TACC (1500 t), with reductions to 1375 t, 1250 t, 1000 t, and 500 t.

Two options were investigated for future recreational catch: firstly, a constant exploitation rate at the level estimated from the MPD in 2004 was assumed (denoted Frec); and secondly, a constant catch at the 2004 level was assumed, i.e. either 300 t or 600 t (denoted Rcap). The first option has recreational catch proportional to stock biomass, i.e. recreational fishing effort and catchability is constant, and catch is not limited. The second option assumes control of the annual recreational catch to the specified level independent of stock biomass. Therefore, two projections were run for each option, producing four scenarios.

Performance indicators calculated over a 5 year projection period included the expected biomasses at the start of the 2005 (E[B_{05}]) and 2010 (E[B_{10}]) fishing years, the expected relative change in biomass after 5 years (E[B_{05}/B_{10}]), the probability of an increase in biomass (P(B_{10}>B_{05}), the expected annual recreational catch in 2010 (E[$C_{rec,10}$]), and the expected future biomass relative to B_0 (E[B_{10}/B_0]). The long-term performance indicator calculated was the expected year in which stock biomass would increase to the 0.2B_0 level (E[t: $B_t = 0.2B_0$]). For each indicator the mean and 90 percentiles of the predicted posterior distribution were calculated.

5. Model results

5.1 Model point estimates

Only the MPD estimates for the R300 and R600 options are presented. Differences between the R300 and R600 and the other options are discussed in Section 5.3.

A good fit to the single trawl catch-at-age data from 1991 to 2004 was obtained (Figure 11), with consistency between the model predictions and the observed progression of strong and weak age classes between years, and also between the model predictions and the observed low abundance of fish in the old age classes. No consistent patterns with respect to either the predicted proportions at age or age class are evident in the standardised Pearson residuals (Figure 12). Similar results were obtained for the pair trawl catch-at-age data from 1986 to 2004, (Figures 13 and 14).

A reasonably good fit was obtained to the single trawl catch-at-age observations in 1975 and 1976 (Figure 15). The strength of the 20+ age class was well predicted by the model in all years except 1974 (Figure 15), possibly because in 1974 landings were sampled during the winter months only (Table 6), whereas in other years samples were collected largely in summer months. It is likely that the single trawl catch-at-age distribution is not well represented by the 1974 data. The effect of the 1974 anomaly is evident in a slight downwards trend with age in the standardised Pearson residuals (Figure 16).

Fits to the pair trawl catch-at-age data from 1975 to 1980 are generally good. The 20+ cohort was predicted well in all but the 1976 observations (Figure 17). The 1976 observation contrasts strongly with those made in 1974 and 1975 when lower proportions in this age class were sampled. The standardised Pearson residuals exhibited no consistent patterns with respect to either the predicted proportions at age, or the age class (Figure 18).

The fit to the research trawl survey recruitment indices for 2+ y fish was good, with no consistent patterns evident in the residuals (Figure 19). Similarly, the fit to the indices for 3+ y fish was relatively good, but the fit to 1984 and 1996 year classes surveyed as 3+ y fish was rather poor (Figure 20). This may be expected given the relatively high error assumed for these observations.

A relatively good fit to the catch-at-age and trawl survey recruitment indices suggests that consistency exists between these two sources of information on year class strengths.

Although a reasonably good fit was obtained to the right hand limb of the at-sea catch-at-length samples from the pair trawl fishery in 1986 for length classes greater than 37 cm, the model predicted a mode in the distribution that was 1 to 2 cm smaller than that observed (Figure 21). This feature was not evident in the standardised Pearson residuals, most likely because of the high error assumed for this observation (Table 9).

The fit to the boat-ramp survey length frequency samples of the recreational fishery was relatively good in 1994, but poor with respect to particular length classes in the other years (Figure 22). The effect of the stepwise change in the selectivity-at-length is evident in the difference in fit for the length classes at and below the MLS. A 1–2 cm shift in the predicted length mode was obtained using the post-1994 selectivity-at-length function. This is clearly visible in the fit to the observation in 1996 (Figure 22). However, the model consistently predicted lower proportions at length than were observed in 1991, 1994 and 2000 for length classes less than 30 cm, resulting in large positive Pearson residuals (Figure 23). Although a number of large positive residuals were derived for the large length classes (greater than 70 cm), these classes made up a negligible fraction of the observed proportions at length. The lack of fit for the small length classes in 1991, 1994 and 2000 was not appreciably improved by the stepwise change in selectivity.

Generally the fit to tag-recapture estimates of population length composition in 1990 and 2002 was good, with the predicted mode corresponding closely to that observed in each year (Figure 24). Although the fit to the observed right-hand limb of the distribution was relatively good in 1990, the model failed to predict the large mode centred on the 63 cm length class in 2002 (Figure 24). The tag-recapture estimate of the 63 cm length mode may be poorly estimated in that it was derived from a relatively low number of recaptures (Davies et al. 2006). This discrepancy is discussed further in Section 5.6.1. The lack of fit produced a large positive residual for the 63 cm length class; however there is no clear pattern in the standardised residuals for the other length classes (Figure 24).

The model predicted lower catch rates for the early part of the pair trawl CPUE time series (1974–76) than were observed, and slightly higher rates in the mid-1980s (Figure 25). These patterns were typical of fits to CPUE data. The residuals were somewhat larger than the assumed variance would predict (Table 11). In the single trawl series (1996–2004) a gradual, steady decline was observed to 2001 with a subsequent increase to 2003, but the model predicted a flat trend to 1999 with a slight increase to 2002 (Figure 25). These differences are relatively minor and consistent with the assumed variance. No patterns were indicated in the residual plots.

The model predicts a gradual biomass decline from the B_0 (110 000 and 116 000 t for R300 and R600, respectively) in 1931 (Table 12) to around 100 000 t by the late-1950s, followed by a steep decline to around 9 000 t in the mid-1980s, increasing slightly by the early-1990s with a relatively flat trajectory to 2003 (Figure 26). Although model biomass is higher than both the 1990 and 2002 observed absolute estimates, particularly in the R600 option, the fit is within approximately one standard deviation of the observed value in both cases (Table 11). Following the steep decline in the 1970s and the first part of the 1980s, there is an increase in biomass consistent with reduced catches following the introduction of a TACC under the Quota Management System (QMS) in 1986 and increases in individual growth rates in 1989 and 1990 (Davies et al. 2006). The decrease in growth in the early part of the 1990s and the recruitment of weak year classes in the late 1980s contribute to the subsequent decline in predicted biomass in the early part of the 1990s. A flat biomass trajectory is predicted from 1993 to 2002, with a slight decline to 2004 (Figure 26). Current biomass is predicted to be 10% B_0 (Table 12).

Apart from the tag-recapture absolute biomass estimates, there is no substantial difference in the fit between the R300 and R600 options to any of the observation types. The higher recreational catch R600 option produced a marginally better overall fit, as indicated by the lower total log-likelihood (Table 13). This was due to slightly better overall catch-at-age and length fits, however to achieve this the fits to the absolute and relative biomass observations were slightly poorer (Tables 11 and 13). Relative to the biomass trajectory of the R300 option for the recent period, the R600 trajectory is consistently higher by an offset of approximately 2 000 t, while maintaining the same relative trend (Figure 26). The R600 option estimates of mean recruitment and natural mortality are 15% and 8% higher (respectively) relative to the R300 option (Table 12). The conclusion is that the model productivity and absolute biomass estimates are sensitive to the assumed historical recreational catch.

5.2 Relative weight of input data

Although the absolute biomass likelihood terms are relatively small, they have considerable leverage on the fit. This was determined from an exhaustive range of options tested, with particular observation types excluded from the objective function. Although these tests indicated slight conflict between the 2002 tag-recapture population length composition and the single trawl CPUE, they showed a generally high level of consistency between the observation types. The R300 and R600 MPD fits illustrate this consistency.

The standard deviations of the standardised residuals were reasonably close to 1.0 for the trawl survey recruitment indices, tag-recapture population length compositions, and CPUE time series. The low value obtained for the pair trawl at-sea catch-at-length data reflects the high observation error assumed for this observation. High values were obtained for the recreational catch-at-length data because of the poor quality of fit for particular length classes, and the relatively low observation error that was assumed for this observation type (Table 9). The low standard deviations of the standardised residuals obtained for the catch-at-age data reflect the good fits and the relatively high sampling error assumed (Table 9). It was the opinion of the Snapper Working Group that the catch-at-age should be down-weighted relative to the biomass estimates. This decision resulted in the natural relative weightings between the data that would be implied by the variability of the residuals not being realised.

5.3 MPD model sensitivities

Estimates of productivity and biomass were sensitive to the assumed historical recreational catch, as indicated by differences between the R300 and R600 options. Maximum unfished biomass and current biomass were 6% and 10% higher respectively for the R600 option (Table 12). The fit to the tag-recapture estimates of absolute abundance were slightly poorer. However, the fits to the catch at age data were mostly unaffected (Table 13). Hence, the YCS estimates for the R300 and R600 options were almost identical (Figure 27). Similarly, the fit to population and catch length composition observations were consistent. Overall, the assumption of higher historical recreational catch under the R600 option results in estimates of a generally more productive stock with higher biomass able to maintain higher historical removals. This sensitivity appears restricted to the recruitment and natural mortality estimates in that recreational and trawl selectivity-at-length estimates appeared robust (Figures 28 and 29, respectively). This was assessed by comparing the estimated selectivity-at-length functions to those derived directly from the 2002 tag-recapture programme. Whereas differences with respect to the tag-recapture estimates for single trawl were evident, there were negligible differences between the options.

A conflict between the single trawl CPUE series and the tag-recapture estimate of population length composition in 2002 was made apparent by differences in relative biomass estimates from the Tag02num, Tag02bio and R300 options. The three options differed in the effective relative weight assigned to the 2002 tag-recapture data. Low relative weight (Tag02num) reduced the quality of fit to the tag-recapture estimates of population length composition and absolute abundance, but improved the fit to single trawl CPUE. High relative weight (R300) resulted in an overall declining biomass trajectory (Figure 30). This is consistent with the finding of the 2004 SNA 8 assessment (Davies et al. 2006), and was attributed to the fit to the observed mode of large fish around 63 cm in the population length distribution. This mode was interpreted within the model as a consequence of large historical year class strengths followed by relatively weak recent year classes, producing a declining trend in recent biomass. This trend is not observed in single trawl catch rates, and to a lesser extent, is not consistent with recent catch-at-age observations (Table 13). However, the Snapper Fisheries Assessment Working Group resolved that the assumed relative weight for R300 and R600 options was the most reasonable.

The Y1974 option produced similar fits to the other options despite the lack of a catch history from 1931 to 1973. However this may be partly an artefact of the model’s parameterisation. To address confounding between the parameters, initial population numbers at age and natural mortality, the Y1974 option was assigned the Tag02num MPD estimate of natural mortality. A strong correlation exists between natural mortality and mean recruitment (Davies et al. 2006), so consequently productivity estimates are conditioned by assumptions regarding natural mortality. Therefore, the similarity between the MPD estimates for the Tag02num and Y1974 options may be expected.

5.4 MCMC results

Generally, the R300 and R600 MCMC chain traces revealed no consistent trends that suggested lack of convergence (Figures 31, 32, 33).

Plots of the running mean for the parameter chains (not shown) appeared mostly flat, and no autocorrelations in the chains were detected beyond a lag phase of 5 that suggested that an acceptable sub-sampling interval was used. The Geweke convergence diagnostic plots (not shown) revealed few points beyond a Z-score of 2, with a normal spread around zero and no consistent patterns. The Raftery and Lewis test confirmed the chain length and sampling interval to be sufficient.

The estimated posterior distributions for mean recruitment from the Tag02bio and R300 options were similar (Figure 34). This suggests that the estimated uncertainty in this parameter is not strongly dependent on the assumed error in the tag-recapture observation of absolute biomass. For the R300 and R600 options the posterior distributions for mean recruitment differ with respect to their median values (Figure 34) while their spreads are similar (Table 14). The estimated posterior for mean recruitment from the Y1974 option indicates greater uncertainty; consistent with fewer assumptions being made regarding historical catches.

Differences were visible between the estimated posterior distributions of the selectivity parameters compared and their priors (Figure 35). The posteriors are narrower than the priors suggesting that the data contained information for estimating selectivity-at-length. There is little difference in the posterior estimates for selectivity between the R300 and R600 options (Figure 35).

While the median of the posterior estimate of current absolute biomass appears sensitive to the assumed recreational catch history, there is little difference between the credibility intervals of the current stock size relative to unfished biomass for the R300 and R600 options, indicating a current stock size of 8% to 12.5% of B_0 (Table 14).

5.5 Comparison with 2004 assessment

A summary of the main changes made to the assessment model presented here, relative to that used for the 2004 assessment includes: additional observations for trawl catch-at-age, recreational catch-at-length, and pair trawl catch-at-length; assumed individual growth rates for 1975, 1976 and 1979; estimated recreational selectivity-at-length, with an assumed stepwise change in the length at maximum selectivity; and alternative statistical assumptions regarding the fit to the 2002 tag-recapture absolute population estimate.

Including additional observations for pair trawl and single trawl catch-at-age in the 1970s gave the models better power to estimate natural mortality given that more observations of fish in the 20+ y aggregate age class were available. Fish in this class retain an age composition that reflects historically low fishing pressures (pre-1950s). The additional observations were consistent with those used in the 2004 assessment with the aggregate age class making up a high proportion of catches. There was a close similarity between the MPD estimate of natural mortality (0.051–0.055) and the median of its posterior (0.057) estimated in 2004 (Davies et al. 2006).

The addition of the boat ramp recreational length-frequency data gave the model power to estimate a stepwise change in the recreational line selectivity-at-length. In contrast, the 2004 assessment used a constant recreational selectivity-at-length based on the 2002 tag-recapture estimate of single trawl selectivity-at-length. A clear difference exists between this function and that estimated from the updated assessment model (Figure 28), with a nearly 10 cm decrease in the length at which selectivity falls to 50% in the right-hand limb. Although a steeply domed function was estimated, the model was unable to predict the observed high proportions caught in length classes less than 30 cm in some years. This may have been due to the double normal selectivity function being inappropriate for recreational selectivity. The Snapper Working Group also thought that temporal and spatial differences in population length composition between harbours and offshore may have caused some of the inconsistencies seen in the recreational catches between years.

A recommendation arising from the 2004 assessment was for a stepwise change in selectivity-at-length for the recreational method to describe a change in the MLS. The updated assessment model does this, and the effects were visible in the estimated catch-at-length before and after 1994.

Including a single observation of pair trawl catch-at-length in 1986 did not substantially influence the estimate of pair trawl selectivity-at-length relative to that estimated in the 2004 assessment (for the Seltot model option, Davies et al. 2006). The right-hand limbs of both estimated functions coincide closely with that of the 2002 tag-recapture estimate. However, the 2004 assessment showed the a_1 parameter to be sensitive to the statistical assumption regarding the fit to the 2002 tag-recapture population length composition. The estimate of a_1 obtained from the updated assessment was more similar to that estimated from the Sel56 model option examined in the 2004 assessment.

In the 2004 assessment there was an inconsistency in the assumptions made in the Sel56 model option (excluded observations in length intervals greater than 55 cm). Here biomass obtained from fish greater than 55 cm was effectively reallocated to fish less than 55 cm (Davies et al. 2006). All of the updated model options include the tag-recapture observations over the entire length range in the fit.

A lower constant mean individual growth rate has been assumed in the updated assessment for the years lacking observations (1931 to 1973), than was assumed in the 2004 assessment. However, the effects of this are confounded with the revised assumption made regarding natural mortality. For the Ref model option used for the 2004 assessment, a constant natural mortality rate of 0.075 y^{-1} was assumed; significantly higher than the estimates from the updated assessment (0.051–0.055 y^{-1}). Consequently, mean recruitment estimates are lower for the updated assessment. Using a comparison with the 2004 Mest model option where natural mortality was estimated at 0.057 y^{-1}, the lower assumed growth rate contributed to a considerably lower estimate of unfished equilibrium biomass (-18%). Only a slight associated increase in mean recruitment is evident, suggesting that other parameters may have also contributed to this difference, e.g. method-specific selectivity-at-length. However, this does highlight the importance of assumptions relating to fundamental biological parameters that alter model productivity estimates and model quantities used for reference points. Despite this difference in initial biomass, the general shape of the trajectories estimated from the 2004 and updated assessments are similar.

Although there are notable differences between the 2004 and updated assessment models, the general conclusion of the assessments with respect to current stock status is similar, i.e., the population biomass is at around 10% of the unfished equilibrium level (Davies et al. 2006). In absolute terms, the range of current biomass estimates is also similar, 9600 to 11 500 t for the updated assessment, and 9200 to 12 100 t for the 2004 assessment. A more valid comparison made with respect to the 2004 model option having natural mortality as a free parameter, (Mest), indicates that the updated assessment is slightly more optimistic, with the population at 9.5% of the unfished equilibrium level, relative to 8.5% for the Mest option. This may be attributed to the lower estimate of unfished equilibrium biomass in the updated assessment model.

The broadly similar results may reflect the constraining influence of the 2002 tag-recapture estimates, but also the relatively slight influence of the updated estimates of recreational selectivity-at-length and natural mortality on predicted stock status.

In the 2004 assessment, a significant structural improvement was made to the population model to better describe fishing mortality and growth. In each year the length distribution of each age-class is derived from the annual length-at-age vector and the coefficient of variation. This length distribution is used to define the method-specific fishing mortality at age given the estimated method-specific selectivity-at-length function. Given the observed interannual variability in growth in SNA 8, modelling fishing mortality as a length-based process applied with observations of annual length-at-age may avoid potential bias incurred by assuming constant selectivity-at-age. For the updated assessment this development was extended to include observed length-at-age in the 1970s, that was assumed to reflect historical growth rates pre 1974.

5.6 SNA 8 stock assessment

5.6.1 Model estimates for 1931 to 2004

The assumption regarding mean length-at-age determines estimates of unfished equilibrium biomass and sustainable yields. The sensitivity of equilibrium yield estimates to assumed mean growth rate was examined under the R300 model option (Table 15). Two growth rates were assumed, one for 1931–2004 and the other for 1989–2004. Under the recent, higher growth rates, *MSY* was marginally higher, and the exploitation rate and biomass at B_{MSY} lower. For both growth rates B_{MSY} was less than 20% of the maximum unfished biomass (Table 15). However, if growth rates are density dependent then they will be slowest at B_0 and substantially faster at B_{MSY}. Hence B_{MSY} will be a higher proportion of B_0 than if it were calculated under a constant growth. No functional relationship has been formulated for this density dependent process in snapper and therefore no corresponding estimate of B_{MSY}/B_0 is available. Given this uncertainty regarding B_{MSY}/B_0, the Snapper Working Group agreed on 20%B_0 as a reference level against which to assess current and future stock status. This level has been used as a threshold for other New Zealand stocks e.g. hoki (Francis 2005).

The updated assessment fulfils the recommendation made in 2004 to include all available observations of mean length-at-age from years prior to 1989. In assuming a constant slower historical growth for these years, the estimates of mean recruitment and B_0 have increased and decreased, respectively, relative to a comparable model option assuming historical growth equivalent to that observed in recent years.

As in the 2004 assessment, a feature of the updated assessment model is the general consistency in the fits to the range of observations, that was reasonably good within the statistical assumptions made. Conflict between the tag-recapture estimate of the population length distribution for the length intervals greater than 55 cm and the single trawl CPUE time series, is the only notable exception to this. This conflict as also apparent in the 2004 assessment, but was further explored in the current assessment by including model options with alternatively high or low weighting on the 2002 tag length composition estimates. The Tag02num option assumed a high weighting, while the R300 and R600 options assumed a low weighting. This range revealed relatively low sensitivity in estimates of current stock size relative to B_0, with both options giving values of between 9 and 10%.

The Bayesian credibility intervals for R_0, and hence B_0 were narrow for all the model options apart from Y1974 (Figure 34), but it is unlikely that the true uncertainty in B_0 is represented by the posterior distribution estimate for any one model option for a number of reasons. Firstly, the credibility intervals are dependent upon the assumptions made regarding historical catches. The model may be described as a “total catch history model” (Gilbert 1994) in that a time series of catches from 1931 to 2004 is assumed to be known exactly, including unreported catches, such as those of the Japanese longline fishery. The Y1974 option has higher uncertainty, making fewer assumptions regarding unreported historical catches. Unfortunately, the posterior distribution for this option is not well estimated because natural mortality had to be assumed constant. However, this option still shows higher uncertainty. The posterior for this option also illustrates the sensitivity to the length-at-age assumed for calculating B_0. The mean of the recent period in which faster growth occurred was used, causing the median of the posterior distribution to be higher than for other model options (Figure 34). Secondly, the marginal posterior distributions for all the options were calculated under a constant value for natural mortality equal to that estimated from the MPD fit. Were the posterior for this parameter to be estimated using the MCMC, a wider credibility interval would be obtained for B_0 (Davies et al. 2006). It is recommended for future assessments that the effects of the high correlation between M and R_0 on the MCMC search algorithm be resolved, permitting the posterior distributions for both M and R_0 to be estimated. Thirdly, of the wide range of observation types to which the model was fitted over the period 1974 to 2004, the catch-at-age data in the 1970s had moderate leverage on the estimates of R_0 and M. The model biomass must remain above zero in the mid 1980s while also maintaining a fit to the low absolute abundance estimates from the later tagging programmes. It is therefore constrained above and below and hence the credibility intervals for B_0 for each option are narrow. For future assessments, it is recommended that these constraining influences be resolved to quantify the relative leverage of each data type. For this assessment, an indication of the “true” uncertainty in B_0 may be represented by the range estimated over all options.

The estimates of current biomass, both absolute and relative to B_0, appeared to be relatively robust. MPD estimates of B_{04} from the various options lay within a relatively narrow range of 9600 to 11 500 t, with B_{04}/B_0 having a range of 8.7% to 9.8%. For the two options selected by the Snapper Working Group for the updated assessment, R300 and R600, B_{04}/B_0 was 9.5% and 9.8% respectively, and the 90% credibility intervals ranged between 7.8% and 12.5%. The sensitivity of B_0 and current biomass to the assumed recreational catch history directly scaled the biomass trajectory such that estimates for the R600 option were proportionally higher than the R300 option (Figure 36). The ratio of current biomass to B_0 was consistent nevertheless. Similarity in the trends of the trajectories most likely reflects the leverage of the range of observation types on the fit through the recent period, 1989 to 2004.

Biomass trajectories between 1931 and 1990 from the R300 and R600 options had almost identical trends, and relatively narrow credibility intervals, particularly through the period 1971 to 1990 (Figure 36). This reflects the constraining influences described above. Credibility intervals widen in recent years with the 90% range for B_{04} being 8.5 to 14.6 kt.

The estimates of current stock size relative to B_0 indicate that the stock is overfished relative to a preferred stock size of 20% B_0. For the R300 and R600 options current stock size is around 50% of this level. This stock status entails some risk of further decline given the possibility of a future period of low YCS as occurred in the late 1980s and early 1990s.

5.6.2 Stochastic projections and performance indicators

Under all the model options and future catch scenarios, SNA 8 biomass is predicted to increase on average (Figure 37). The rate of increase, and hence the probability of achieving the $0.2B_0$ level within 20 years is considerably lower for the Frec scenario compared with the constant recreational catch scenario, Rcap (Figure 38). Underpinning this effect is the predicted increase in recreational catches that occurs as the stock rebuilds (Table 16). Under a rapid population increase resulting from a TACC of 500 t, high abundance in the smaller length classes are predicted to rapidly increase recreational catches up to 800 t for the R300 option, and to over 1400 t for the R600 option (Figure 39).

Of the two options investigated, the R300 option predicted the most optimistic scenarios. Under the current TACC, the best performing was the R300_Rcap option where almost a 50% probability of achieving the reference biomass by 2025 was estimated (Figure 38). The R600_Frec option performed the worst, with a negligible expected increase in biomass by 2025.The R600 option predicted a lower rate of relative increase in biomass in the future. Because the R600 option increases the historical catches more in the recent past than in the distant past, the increase in total productivity that results does not fully compensate for the higher catches continuing into the future.

In the absence of all fishing, biomass is predicted to increase to the reference $0.2B_0$ level by 2010 (Table 16). For all the model options the rate of increase is substantially improved with a reduction in the TACC. However, for the R600_Frec option at least a 33% reduction is required to increase the stock size to the reference level within a 20 year timeframe (Table 16). Under a constant future recreational catch, the predicted stock increase is consistent and relatively rapid, between 17% and 25% over the next 5 years under a 17% TACC reduction (TACC 1250 t).

The uncertainty in the predictions is relatively high. The lower 90% credibility interval of the performance indicator of probability of increase over the next 5 years, suggests that declines in biomass are possible. This most likely reflects the estimated high year class strength variability for SNA 8 that frequently produces weak year classes. Periods of weak or strong year classes can produce rapid temporary declines or increases in biomass.

5.7 Yield estimates

Deterministic equilibrium yield estimates were calculated for the R300 option assuming a catch split between the fishing methods based upon the commercial catches in 2004, and the assumed recreational catch. All yield estimates include a commercial catch history with under-reporting which is assumed to continue at 10% in future years.

5.7.1 Estimation of *MSY*

MSY was calculated as the maximum catch that could be sustained by the stock in equilibrium. Sensitivity to the assumed individual growth rate was examined (see Section 5.6.1). For the R300 option this is achieved with a catch to biomass ratio of 8.2% or 9.8% at B_{MSY} and *MSY* is:

$$MSY = 2290 \text{ t or } 2330 \text{ t}$$

5.7.2 Estimation of MCY

MCY was not calculated.

5.7.3 Estimation of CAY

CAY was not calculated.

6. MANAGEMENT IMPLICATIONS

6.1 SNA 8

The updated assessment options R300 and R600 indicate that current biomass is low, and between 8% and 12% of the unfished equilibrium biomass, B_0. Biomass is predicted to slowly increase at the current TACC level, and the rate depends upon the assumptions made regarding future recreational catch and the model option used. For projections examining large reductions in the TACC, the rebuild to $0.2B_0$ occurred after 2010 in all cases, assuming either constant recreational effort, or constant recreational catch at the alternative levels of 300 t or 600 t per year. Increases in biomass were predicted to be slower for projections that allowed the recreational catch to rise with increasing biomass.

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Table 1: Reported landings (t) for SNA 8 from 1931 to 1990.

Year	SNA 8	Year	SNA 8
1931	140	1961	1 178
1932	159	1962	1 352
1933	213	1963	1 456
1934	190	1964	1 276
1935	108	1965	1 182
1936	103	1966	1 831
1937	85	1967	1 477
1938	89	1968	1 491
1939	71	1969	1 344
1940	76	1970	1 588
1941	62	1971	1 852
1942	57	1972	1 961
1943	75	1973	3 038
1944	69	1974	4 340
1945	124	1975	4 217
1946	244	1976	5 326
1947	251	1977	3 941
1948	215	1978	4 340
1949	277	1979	3 464
1950	318	1980	3 309
1951	364	1981	3 153
1952	361	1982	2 636
1953	1 124	1983	1 814
1954	1 093	1984	1 536
1955	1 202	1985	1 866
1956	1 163	1986	959
1957	1 472	1987	1 072
1958	1 128	1988	1 565
1959	1 114	1989	1 571
1960	1 202	1990	1 551

The 1931–43 years are April–March but from 1944 onwards are calendar years. The totals are approximations derived from port landing subtotals, as follows: SNA 8, Paraparaumu to Hokianga. Data up to 1985 are from fishing returns; data from 1986 to 1990 are from Quota Management Reports.

Table 2: Reported landings (t) of snapper in SNA 8 from 1983–84 to 2002–03 and TACCs (t) for 1986–87 to 2002–03.

Fishstock	SNA 8	
QMAs	8, 9	
	Landings	TACC
1983–84†	1 725	–
1984–85†	1 546	–
1985–86†	1 828	–
1986–87‡	893	1 330
1987–88‡	1 401	1 383
1988–89‡	1 526	1 508
1989–90‡	1 550	1 594
1990–91‡	1 658	1 594
1991–92‡	1 464	1 594
1992–93‡	1 543	1 500
1993–94‡	1 542	1 500
1994–95‡	1 434	1 500
1995–96‡	1 558	1 500
1996–97‡	1 613	1 500
1997–98‡	1 589	1 500
1998–99‡	1 636	1 500
1999–2000‡	1 604	1 500
2000–01‡	1 630	1 500
2001–02‡	1 577	1 500
2002–03‡	1 558	1 500
2003–04‡	1 666	1 500

† FSU data. SNA 8 = stat areas 37, 39–48.
‡ QMS data.

Table 3: Reported landings (t) of snapper by Fishstock from 1967 to 1977 by Japanese trawl and longline fisheries (from Annala et al. 2004). NA, not available.

(a) Trawl

Year	Trawl catch (all species)	Total snapper trawl catch	SNA 1	SNA 8
1967	3 092	30	NA	NA
1968	19 721	562	1	309
1969	25 997	1 289	0	929
1970	31 789	676	2	543
1971	42 212	522	5	403
1972	49 133	1 444	1	1 217
1973	45 601	616	0	466
1974	52 275	472	0	363
1975	55 288	922	26	735
1976	133 400	970	NA	676
1977	214 900	856	NA	708

(b) Longline

Year	Total snapper	SNA 1	SNA 8
1975	1 510	761	749
1976	2 057	930	1 127
1977	2 208	1 104	1 104

Table 4: Estimates of annual recreational catch in SNA 8 in numbers and weight* of snapper. NA, not available.

Year	Source	Number caught (millions)	Catch weight (t)
1990	Tagging programme	NA	239
1993–94	Telephone and diary survey	0.36	238
1996	Telephone and diary survey	0.28	240
2000	Telephone and diary survey	0.65	661
2001	Diary survey	1.11	1 133

* Mean weight was based on boat ramp survey data for SNA 8.

Table 5: Standardised CPUE indices for SNA 8 single trawl fishery.

Fishing year	**Index**	**c.v.**
1995–96	1.15	0.05
1996–97	1.01	0.03
1997–98	0.96	0.02
1998–99	0.92	0.03
1999–00	0.90	0.02
2000–01	0.83	0.02
2001–02	0.98	0.02
2002–03	1.20	0.03
2003–04	1.12	0.02

Table 6: SNA 8 single trawl and pair trawl catch-at-age samples collected from 1974 to 1980 with the number of landings (*k*) and otoliths (*n*) collected each month. Shaded cells indicate the monthly samples that were used for in the 2004 assessment.

Pair trawl

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1974					*k*=4 *n*=459						*k*=4 *n*=389	
1975					*k*=4 *n*=342						*k*=4 *n*=417	*k*=1 *n*=99
1976												
1977												
1978		*k*=4 *n*=419		*k*=5 *n*=666		*k*=2 *n*=210		*k*=2 *n*=208		*k*=4 *n*=342	*k*=4 *n*=373	*k*=2 *n*=181
1979	*k*=3 *n*=301					*k*=3 *n*=326		*k*=2 *n*=224			*k*=2 *n*=169	

Single trawl

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1974					*k*=3	*k*=1					*k*=2	*k*=4

					n=249	*n*=121					*n*=125	*n*=309
1975					*k*=3 *n*=258						*k*=3 *n*=218	*k*=1 *n*=72

Table 7: SNA 8 trawl survey indices of year class strength with the ages at which individual year classes were sampled and the year in which recruits enter the population as three-year-old fish. - indicates that the year class was not surveyed.

Year class	Index	c.v.	Age surveyed (y)	Recruitment year
1984	0.80	0.27	3+	1987
1985	2.68	0.28	2+	1988
1986	0.76	0.10	3+	1989
1987	0.65	0.20	2+	1990
1988	0.17	0.37	3+	1991
1989	0.94	0.32	2+	1992
1990	-	-	-	-
1991	1.24	0.15	3+	1994
1992	0.77	0.26	2+	1995
1993	0.91	0.31	3+	1996
1994	0.87	0.20	2+	1997
1995	-	-	-	-
1996	1.90	0.13	3+	1999
1997	0.29	0.19	2+	2000

Table 8: Estimates of biological parameters for SNA 8.

Estimate				Source
1. Instantaneous rate of natural mortality (*M*)				
			0.075	Davies (1999)
			0.051–0.055	This assessment
2. Weight = $a\ (length)^{b}$				
(Weight in g, length in cm fork length)				
			a = 0.04467 b = 2.793	Paul (1976)
3. von Bertalanffy growth parameters				
(both sexes combined)				
	K	t_0	L_∞	
	0.160	-0.11	66.9	McKenzie et al. (1992)
1975–79	0.160	-1.41	54.0	This assessment
1989–2004	0.101	-2.18	68.2	This assessment
4. Age at recruitment (years)				
			3	Gilbert & Sullivan (1994)

Table 9: Observation error assumed for the data used to fit the SNA 8 population model (*N* is the effective sample size, c.v. is the coefficient of variation), and the process error (added as sampling error) assumed.

Observation type	Observation error	Process error	Error type
Catch-at-age pair trawl (1986 to 2004)	*N* = 13 to 63 (otoliths)	0	Multinomial
Catch-at-age single trawl (1991 to 2004)	*N* = 13 to 72 (otoliths)	0	Multinomial
Catch-at-age pair trawl (1974 to 1980)	*N* = 8 to 86 (otoliths)	0	Multinomial
Catch-at-age single trawl (1974 to 1976)	*N* = 7 to 35 (otoliths)	0	Multinomial
CPUE pair trawl 1974-1991	c.v. range = 0.1 – 0.3	0.2	Log-normal
CPUE single trawl 1996-2003	c.v. range = 0.02 – 0.05	0.2	Log-normal
Tag biomass 1990	c.v. = 0.18 or 0.30	0	Log-normal
Tag biomass 2002	c.v. = 0.12 or 0.20	0	Log-normal
Tag population proportions at length 1990	c.v. range = 0.11 – 0.48	0	Log-normal
Tag population proportions at length 2002	c.v. range = 0.06 – 7.60	0	Log-normal
Trawl survey 2+ year class strength index	c.v. range = 0.19 – 0.32	0.2	Log-normal
Trawl survey 3+ year class strength index	c.v. range = 0.10 – 0.37	0.4	Log-normal
Boat ramp recreational catch length frequency	*N* = 100	*N* = 60	Multinomial
Pair trawl at-sea catch length frequency	*N* = 10	0	Multinomial

Table 10: Prior distributions assumed for model parameters.

Parameter	Prior	Specification			
Mean recruitment, $\bar{R}$	Uniform-log	Range = (10^4, 10^6)			
Year class strengths (1971–2000)	Uniform	Range = (0.01, 20.0)			
Catchability coefficients (CPUE and trawl survey indices), q_1, q_2, q_3, q_4	Uniform-log	Range = (10^{-9}, 3.0)			
Selectivity (double-normal function) –			a_1	s_L	s_R
single trawl	Normal	mean:	31.3	2.7	17.9
		c.v.:	0.16	0.05	0.11
pair trawl	Normal	mean:	32.0	2.9	22.2
		c.v. =	0.14	0.05	0.38
recreational pre-1994	Normal	mean:	25.0	2.9	12.0
		c.v. =	0.0	0.05	0.5
recreational post-1994	Normal	mean:	27.0	2.9	12.0
		c.v. =	0.0	0.05	0.5
Natural mortality, *M*	Log-normal	Mean = 0.075, c.v. = 0.5			

Table 11: Standard deviations of the standardised MPD residuals for the SNA 8 model options for the various data types: single trawl and pair trawl catch-at-age 1989 to 2004 (STage and PTage, respectively), single trawl and pair trawl catch-at-age 1974 to 1980 (STage70s and PTage70s, respectively), research trawl survey recruitment indices of 2+ and 3+ y fish (TSI_{2+} and TSI_{3+}), at-sea length frequency of pair trawl catches in 1986 (LF_{PT86}), boat-ramp survey length frequencies of the recreational fishery assuming pre-1994 and post-1994 selectivity-at-length ($LF_{Rec,pre94}$ and $LF_{Rec,post94}$, respectively), tag-recapture estimates of population proportions-at-length in 1990 and 2002 (Tag-LF_{90} and Tag-LF_{02}, respectively), tag-recapture estimate of absolute population numbers at length in 2002 (Tag-num_{02}), single trawl and pair trawl CPUE ($CP_{ST96-04}$ and $CP_{PT74-91}$, respectively). The single absolute residual for each of the likelihood terms for the tag-recapture estimates of absolute biomass in 1990 and 2002 ($BTag_{90}$ and $BTag_{02}$, respectively) are presented.

Option	STage	PTage	STage70s	Ptage70s	TSI_{2+}	TSI_{3+}	LF_{PT86}	$LF_{Rec,pre94}$
Tag02num	0.40	0.51	0.89	0.56	0.91	1.21	0.28	1.82

Y1974	0.41	0.50	0.63	0.43	0.91	1.21	0.28	1.90
Tag02bio	0.40	0.51	0.89	0.56	0.92	1.20	0.28	1.83
R300	0.39	0.51	0.89	0.56	0.93	1.19	0.28	1.85
R600	0.40	0.50	0.87	0.53	0.90	1.19	0.28	1.87

	$LF_{Rec,post94}$	Tag-LF_{90}	Tag-LF_{02}	Tag-num_{02}	$CP_{ST96-04}$	$CP_{PT74-91}$	$BTag_{90}$	$Btag_{02}$
Tag02num	1.99	1.07	-	1.09	0.77	1.27	-1.04	-
Y1974	1.95	1.07	-	1.09	0.79	1.27	-1.05	-
Tag02bio	2.02	1.07	1.05	-	0.71	1.27	-1.06	-0.24
R300	2.04	1.07	1.05	-	0.69	1.27	-0.59	-0.21
R600	1.88	1.07	1.04	-	0.75	1.30	-1.03	-0.74

Table 12: Biomass and MPD parameter estimates for the SNA 8 model options. B_0 is virgin stock biomass. B_{90}, B_{02}, and B_{04} are the start of year biomasses for 1990, 2002, and 2004 respectively. B_{04}/B_0 is the ratio of 2004 biomass to B_0. Biomass is thousands of tonnes. R_0 is mean annual recruitment of 3-year-old fish (in millions), and M is natural mortality (y^{-1}). * indicates the estimate for the parameter was assumed from the Tag02num option.

Option	B_0	B_{90}	B_{02}	B_{04}	B_{04}/B_0	R_0	M
Tag02num	109.6	11.6	10.3	9.6	0.087	2.44	0.051
Y1974	109.0	11.7	10.4	9.6	0.088	2.43	0.051*
Tag02bio	109.7	11.7	10.8	10.1	0.092	2.46	0.051
R300	109.8	11.8	11.1	10.5	0.095	2.47	0.051
R600	116.3	13.4	12.3	11.5	0.098	2.84	0.055

Table 13: Negative log-likelihoods for the SNA 8 MPD model options for the various observation data types: single trawl and pair trawl catch-at-age 1989 to 2004 (STage and PTage, respectively), single trawl and pair trawl catch-at-age 1974 to 1980 (STage70s and PTage70s, respectively), research trawl survey recruitment indices of 2+ and 3+ y fish (TSI_{2+} and TSI_{3+}), at-sea length frequency of pair trawl catches in 1986 (LF_{PT86}), boat-ramp survey length frequencies of the recreational fishery assuming pre-1994 and post-1994 selectivity-at-length ($LF_{Rec,pre94}$ and $LF_{Rec,post94}$ respectively), tag-recapture estimates of population proportions-at-length in 1990 and 2002 (Tag-LF_{90} and Tag-LF_{02} respectively), tag-recapture estimate of absolute population numbers at length in 2002 (Tag-num_{02}), single trawl and pair trawl CPUE ($CP_{ST96-04}$ and $CP_{PT74-91}$ respectively), and tag-recapture estimates of absolute biomass in 1990 and 2002 ($BTag_{90}$ and $BTag_{02}$, respectively).

Option	STage	PTage	STage70s	Ptage70s	TSI_{2+}	TSI_{3+}	LF_{PT86}	$LF_{Rec,pre94}$
Tag02num	149.04	101.69	41.85	103.61	-5.04	-1.24	17.06	135.27
Y1974	149.25	101.48	36.81	98.55	-5.04	-1.24	17.04	135.34
Tag02bio	148.77	101.52	41.81	103.56	-4.99	-1.35	17.06	135.30
R300	148.58	101.49	41.78	103.58	-4.95	-1.37	17.06	135.40
R600	149.24	101.37	41.44	102.70	-5.08	-1.38	17.07	135.20

	$LF_{Rec,post94}$	Tag-LF_{90}	Tag-LF_{02}	Tag-num_{02}	$CP_{ST96-04}$	$CP_{PT74-91}$	$BTag_{90}$	$Btag_{02}$	Total
Tag02num	135.83	-33.12	-	24.68	-12.12	-10.93	-1.19	-	645.39
Y1974	135.83	-32.96	-	24.43	-11.97	-11.09	-1.17	-	635.25
Tag02bio	135.89	-33.14	25.72	-	-12.46	-10.97	-1.16	-2.10	643.45
R300	136.01	-33.04	25.68	-	-12.58	-11.00	-1.05	-1.60	643.98
R600	135.56	-33.11	25.27	-	-12.24	-10.42	-0.69	-1.35	643.60

Table 14: Mean of the marginal posterior distributions of biomass for the R300 and R600 SNA 8 model options where B_0 is the unfished stock biomass; B_{04} is the start of year biomass for 2003–04, and B_{04}/B_0 is the 2003–04 biomass as a percentage of B_0. The 90% credible intervals were derived from the marginal posterior distributions. The biomass units are 1000 t.

Option	B_0	5%	95%	B_{04}	5%	95%	B_{04}/B_0	5%	95%
R300	110.3	108.3	112.4	10.8	8.5	13.4	9.8	7.8	12.1
R600	116.6	114.3	119.0	11.7	9.2	14.6	10.0	8.0	12.5

Table 15: Equilibrium yield estimates for SNA 8 calculated using average weight-at-age over the periods 1931–2004 or 1989–2004. *MSY* is the equilibrium maximum sustainable yield (t), B_{MSY} is the equilibrium biomass that supports the *MSY*, (expressed as a percentage of the unfished biomass B_0), and U_{MSY} is the equilibrium exploitation rate that produces *MSY* at the B_{MSY} population level.

Mean weight-at-age	B_{MSY}	*MSY* (t)	U_{MSY}
Constant 1931–2004	18.3%	2 290	0.098
Constant 1989–2004	17.5%	2 330	0.082

Table 16: Projection estimates for the R300 and R600 SNA 8 model options under two alternative future recreational catches: a constant annual recreational catch (*Rcap*), or a constant proportional recreational catch (*Frec*) equivalent to the proportional recreational harvest in 2004. Future recreational catch is consistent with that assumed for in 2004, i.e. 300 t or 600 t for the R300 and R600 options, respectively. Estimates are shown for a range of future TACCs and for a projection under zero removals, i.e. TACC = 0 t and zero recreational catch. B_{05} and B_{10} are start of year biomasses for 2004–05, and 2009–10, respectively. P(B_{10}>B_{05}) is the probability of B_{10} exceeding B_{05} and E[ ] denotes expected value. The 90% credible intervals for B_{10}/B_{05} were derived from the marginal posterior distributions. CR_{2010} is recreational catch in 2010. E[B_y] = 0.2B_0 denotes the year 0.2B_0 is expected to be reached.

(a) R300_Rcap

TACC	E[B_{05}] (t)	E[B_{10}] (t)	B_{10}/B_{05} Expected	5%	95%	P(B_{10}> B_{05})	E[CR_{2010}]	Year when E[By] = 0.2B_0
500	10 891	18 538	1.70	1.29	2.13	1.00	300	2011
1 000	10 882	15 266	1.39	0.99	1.81	0.94	300	2014
1 250	10 869	13 709	1.25	0.83	1.67	0.84	299	2018
1 375	10 866	12 876	1.17	0.74	1.59	0.74	297	2021
1 500	10 904	12 206	1.10	0.71	1.51	0.64	296	>2025

(b) R300_Frec

TACC	E[B_{05}] (t)	E[B_{10}] (t)	B_{10}/B_{05} Expected	5%	95%	P(B_{10}> B_{05})	E[CR_{2010}]	Year when E[By] = 0.2B_0
0	10 929	23 614	2.18	1.77	2.68	1.00	-	2010
500	10 929	17 747	1.63	1.30	2.01	0.96	561	2012
1 000	10 901	14 746	1.35	1.02	1.71	0.96	472	2016
1 250	10 913	13 288	1.21	0.84	1.57	0.83	426	2022
1 375	10 929	12 556	1.14	0.79	1.48	0.75	401	>2025
1 500	10 906	11 778	1.07	0.73	1.43	0.61	376	>2025

(c) R600_Rcap

TACC	E[B_{05}] (t)	E[B_{10}] (t)	B_{10}/B_{05} Expected	5%	95%	P(B_{10}> B_{05})	E[CR_{2010}]	Year when E[By] = 0.2B_0
500	11 693	18 429	1.57	1.17	2.01	0.99	600	2012
1 000	11 713	15 353	1.30	0.87	1.74	0.88	599	2016
1 250	11 683	13 781	1.17	0.76	1.58	0.73	596	2020
1 375	11 676	13 087	1.10	0.70	1.53	0.64	591	>2025
1 500	11 695	12 337	1.04	0.67	1.46	0.53	583	>2025

(d) R600_Frec

TACC	E[B_{05}] (t)	E[B_{10}] (t)	B_{10}/B_{05} Expected	5%	95%	P(B_{10}> B_{05})	E[CR_{2010}]	Year when E[By] = 0.2B_0
0	11 730	25 592	2.20	1.77	2.70	1.00	-	2010
500	11 676	17 346	1.49	1.19	1.84	1.00	1 013	2014
1 000	11 729	14 596	1.24	0.93	1.57	0.90	856	2021
1 250	11 710	13 106	1.11	0.80	1.43	0.71	767	>2025
1 375	11 702	12 419	1.05	0.75	1.39	0.59	726	>2025
1 500	11 700	11 799	1.00	0.70	1.32	0.48	690	>2025

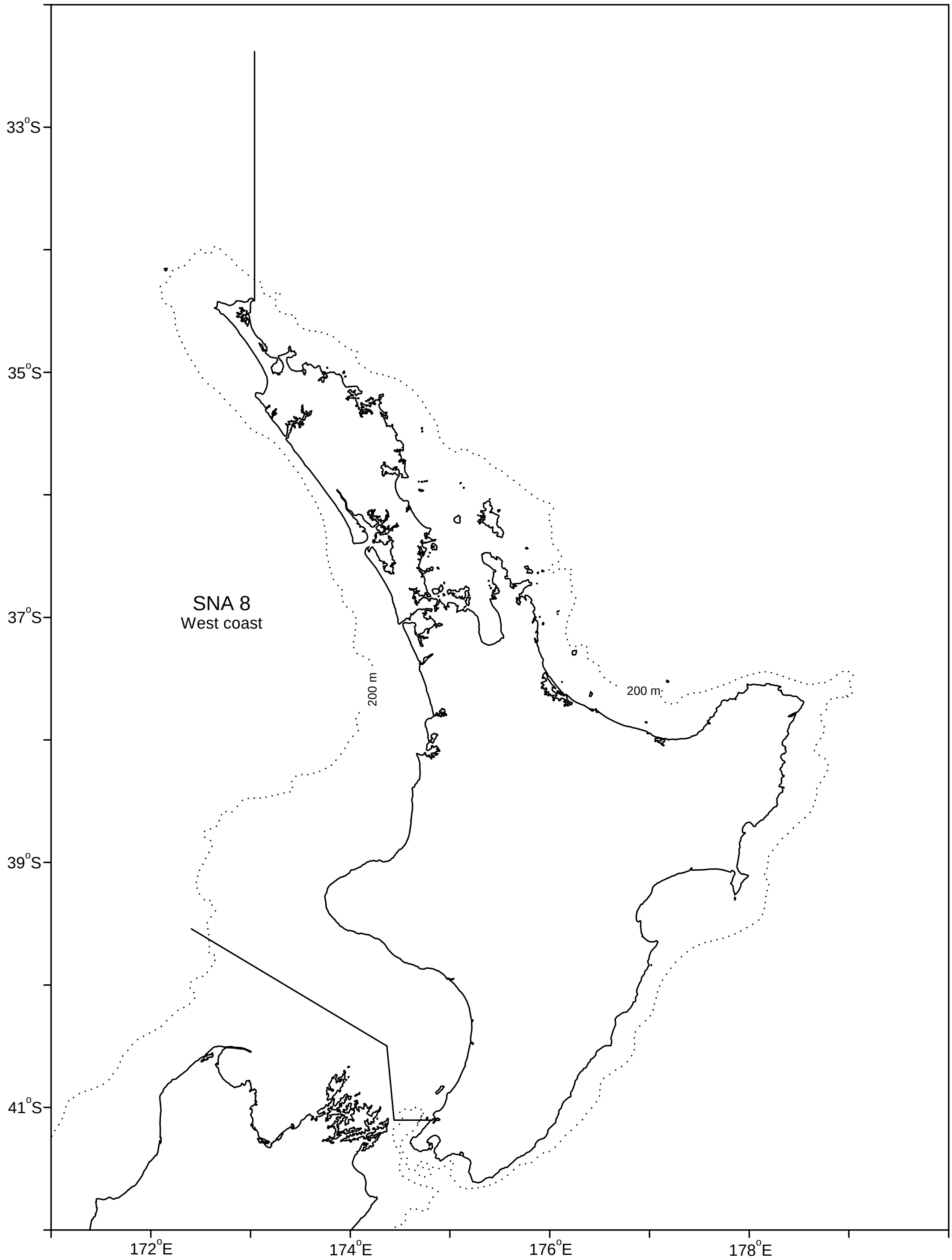


Figure 1: Quota management area for the west coast North Island snapper stock, SNA 8.

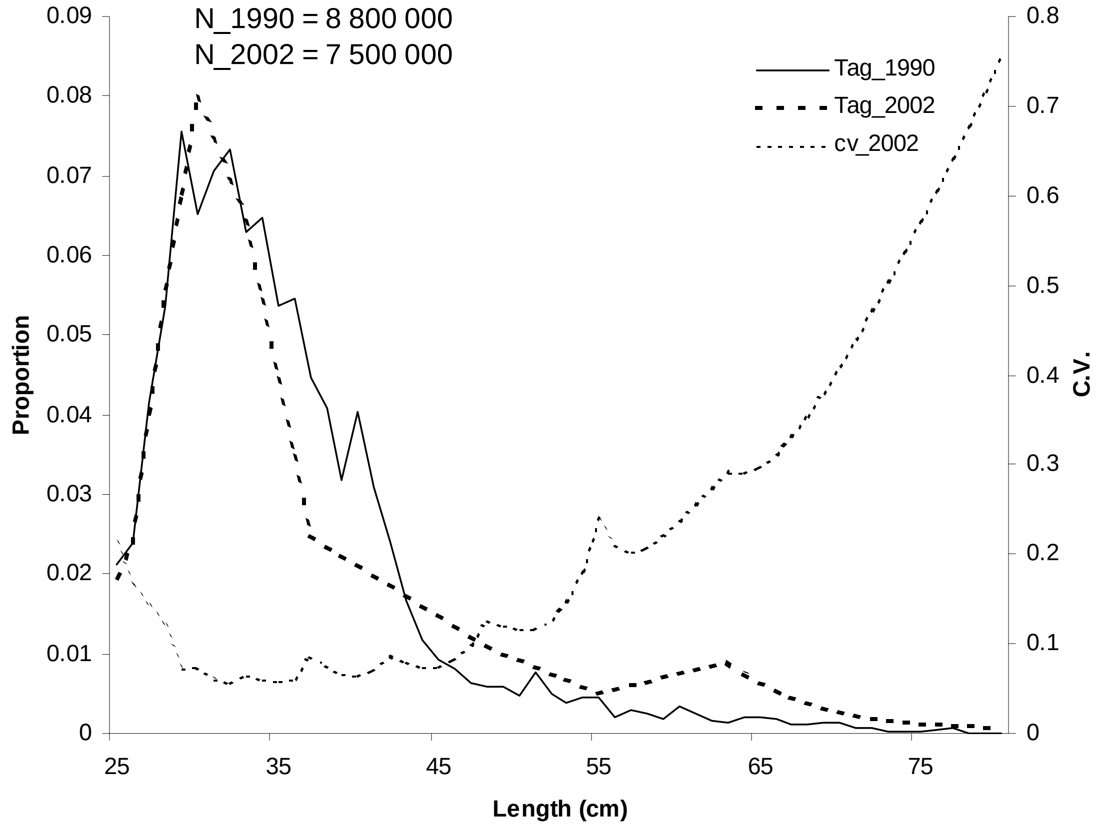


Figure 2: The tag-recapture estimates of absolute population numbers and proportions-at-length for 1990 and 2002 with coefficients of variation for the 2002 estimate.

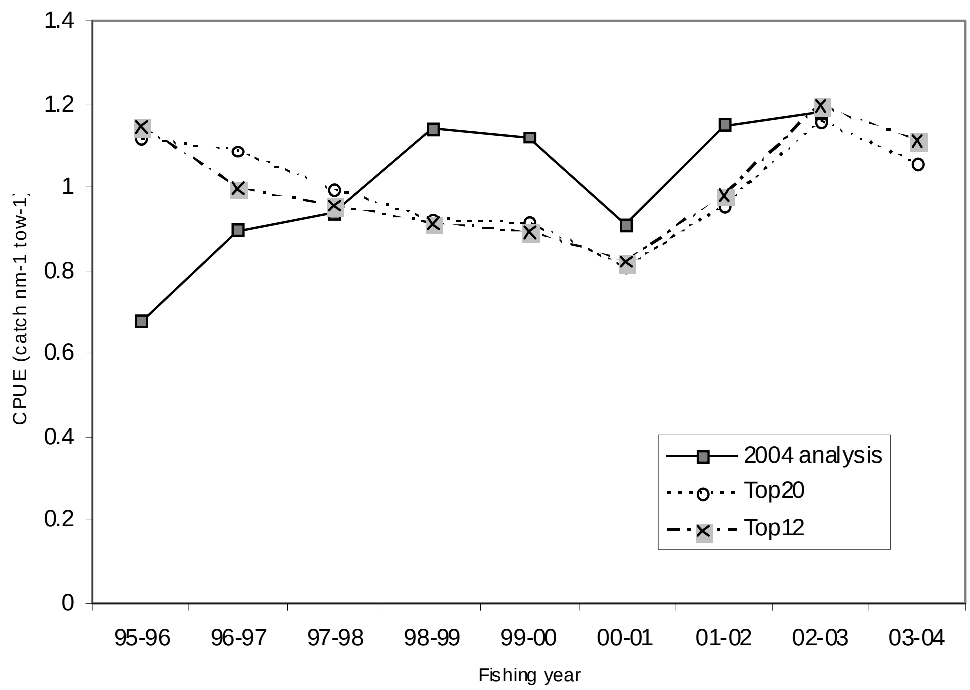


Figure 3: Standardised CPUE indices for single trawl fishery based on individual tow records of catch per nautical mile for the top 12 and top 20 vessels, and the 2004 CPUE indices.

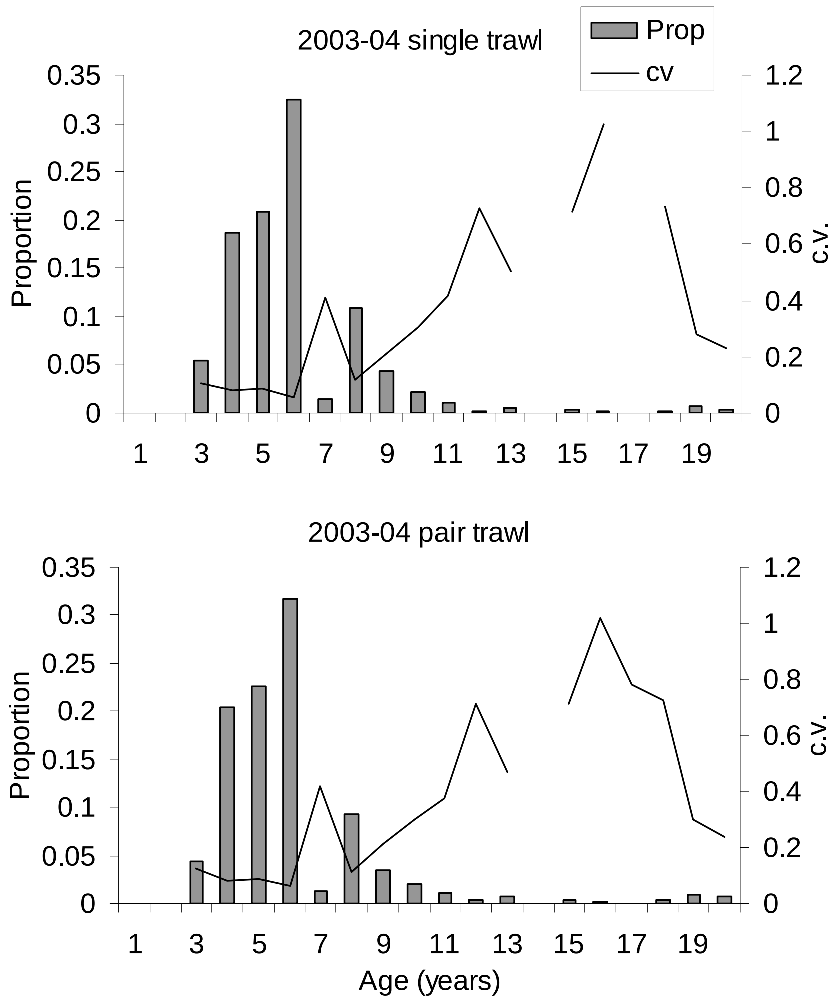


Figure 4: Catch-at-age and c.v.s for the single trawl and pair trawl fisheries in SNA 8 in 2003–04.

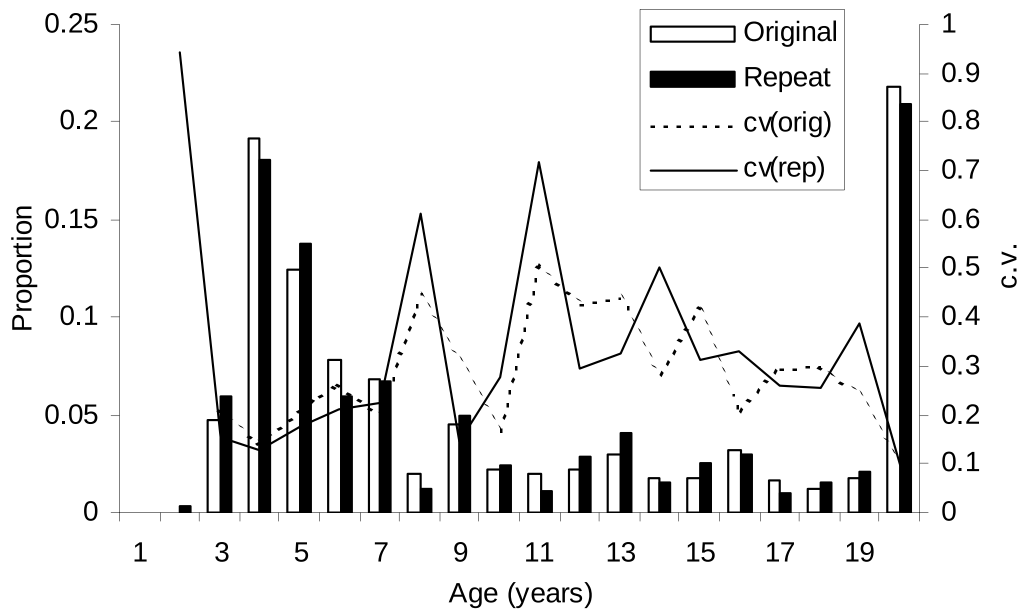


Figure 5: Catch-at-age estimates for pair trawl landings in winter 1974 determined from original otolith readings and repeated readings using current ageing protocols.

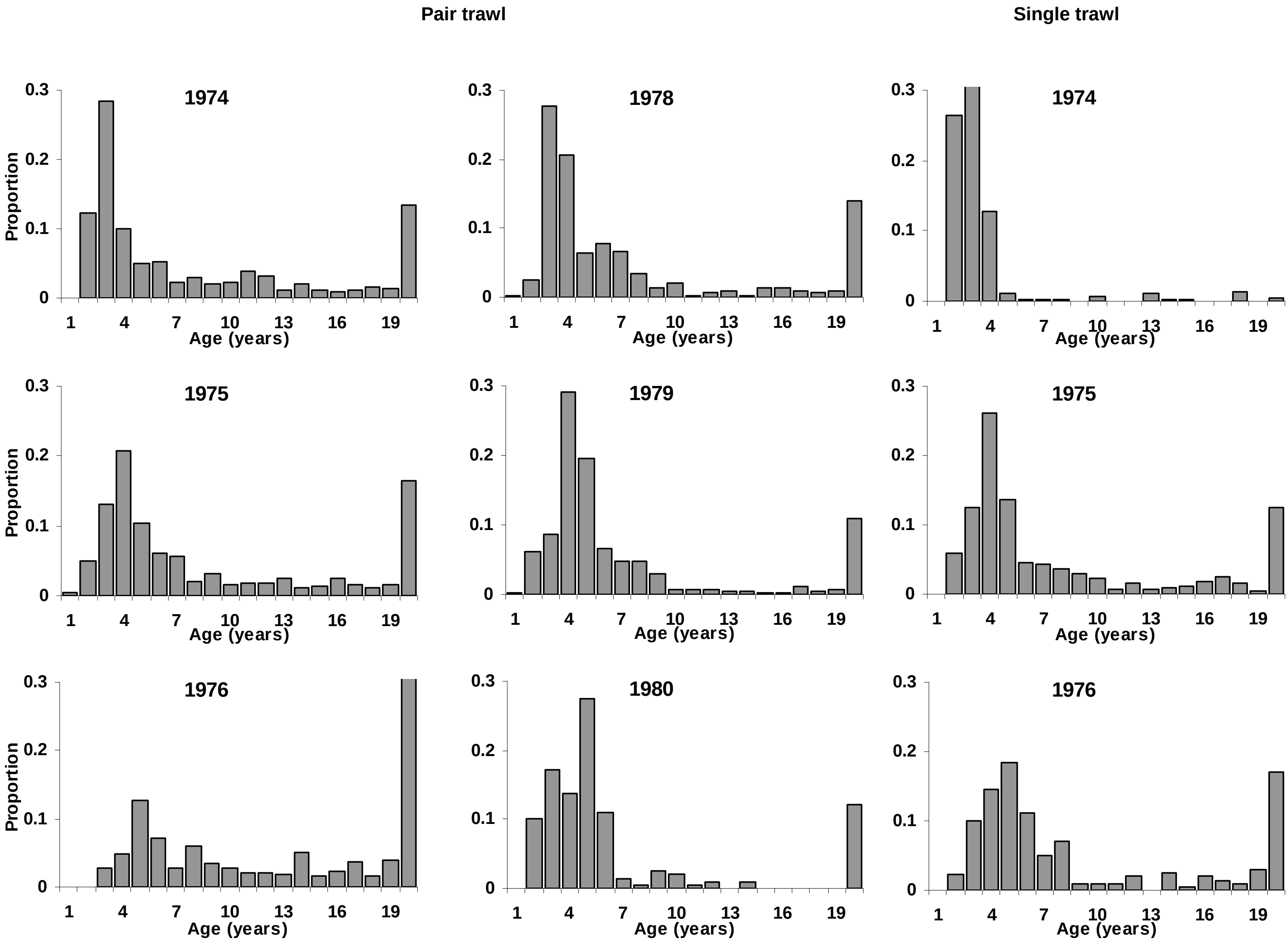


Figure 6: Catch-at-age estimates for pair trawl (left and middle panels) and single trawl (right hand panels) landings from 1974 to 1980.

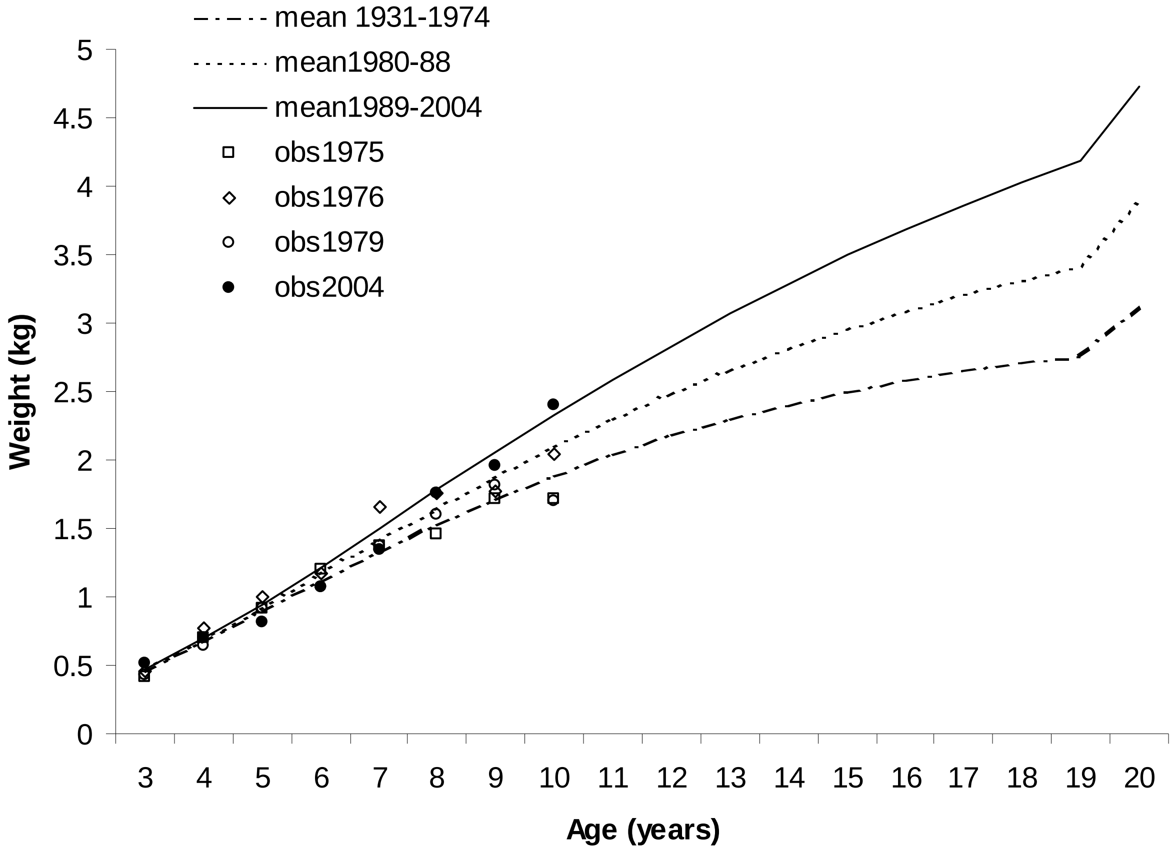


Figure 7: Observed mean weight-at-age for ages 3 to 10 years for 1975, 1976, 1979, and 2004, with the mean von Bertalanffy estimates for all ages for the period 1989–2004, and the estimates assumed for the periods lacking observations: 1931–74 and 1981–88.

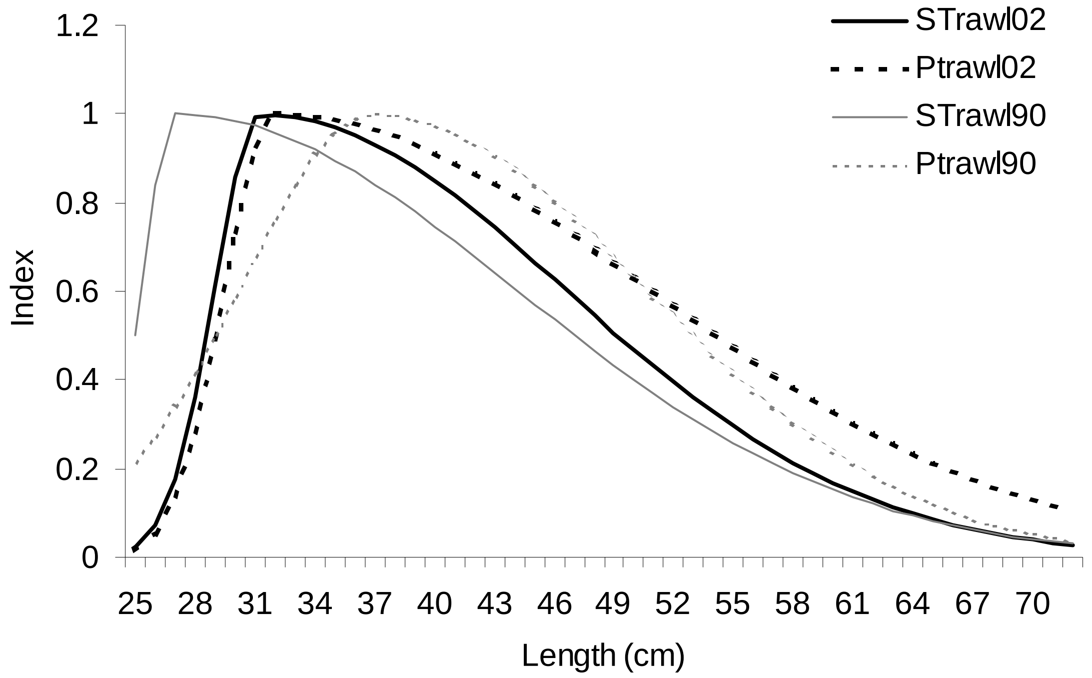


Figure 8: Selectivity-at-length functions estimated from the 1990 and 2002 tag-recapture experiments in SNA 8 for the single trawl and pair trawl methods.

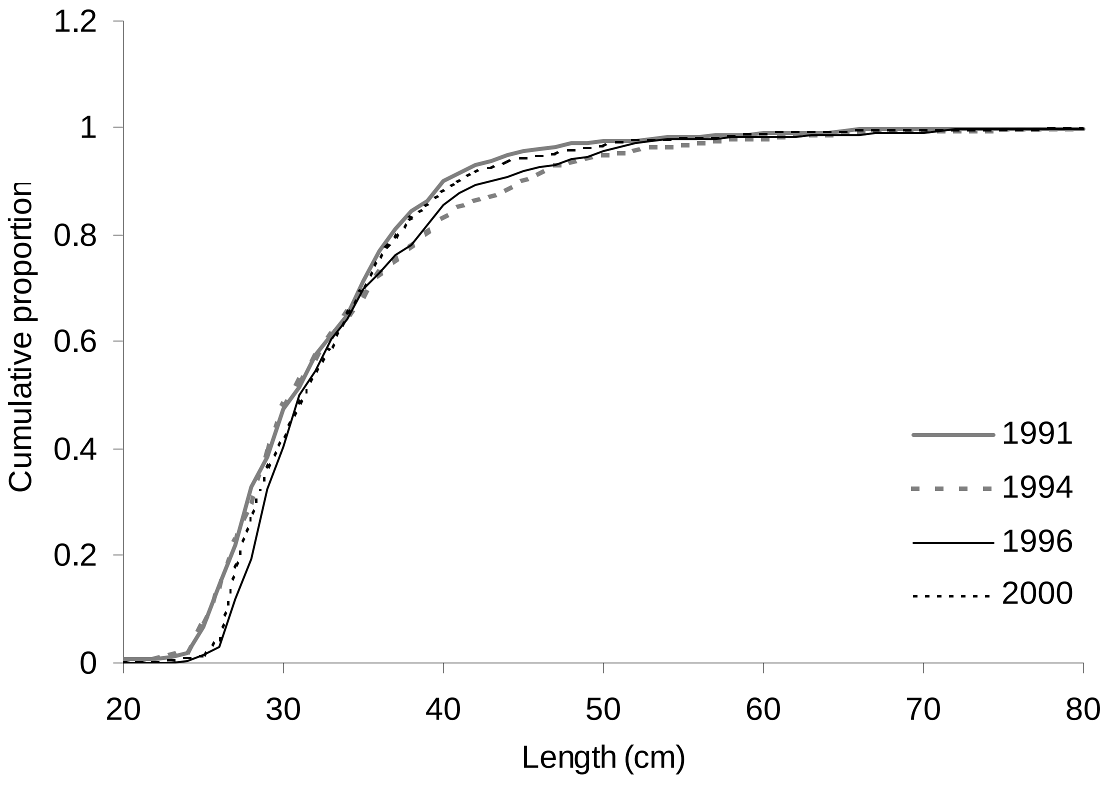


Figure 9: Cumulative proportions-at-length of recreational snapper catch from SNA 8 taken from boat ramp samples in 1991, 1994, 1996 and 2000.

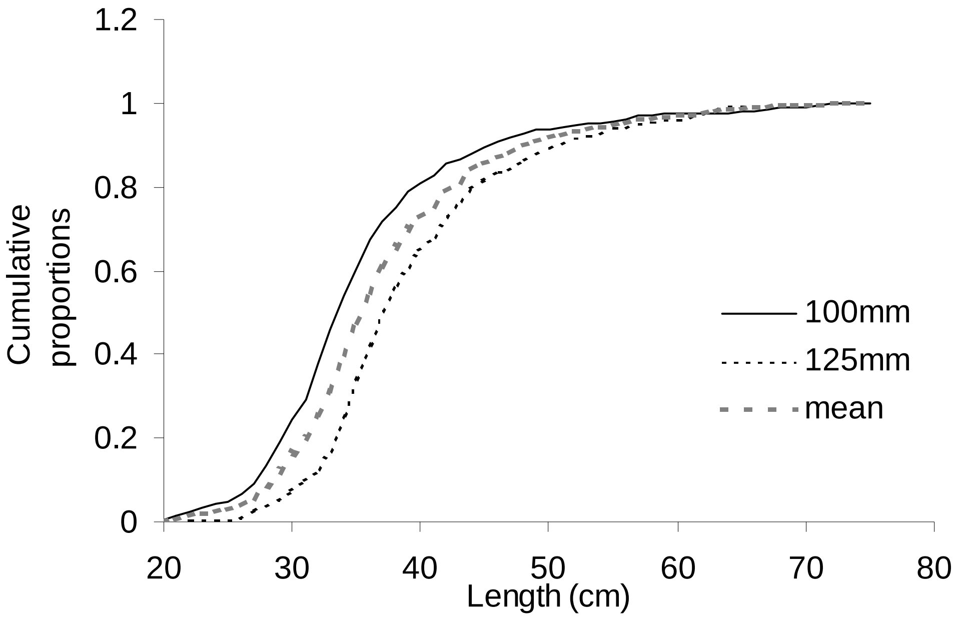


Figure 10: Cumulative proportions-at-length of pair trawl snapper catch from SNA 8 measured at sea from tows using 100 mm and 125 mm cod-end mesh, and the mean proportions-at-length.

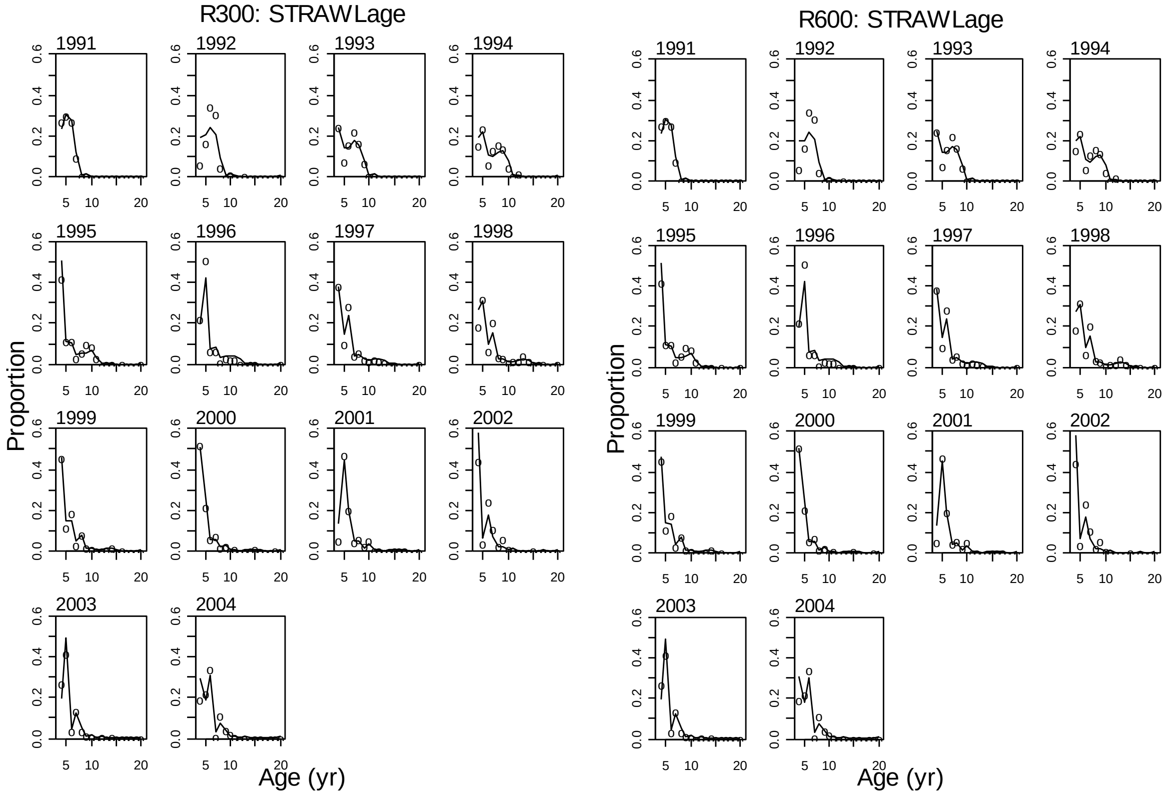
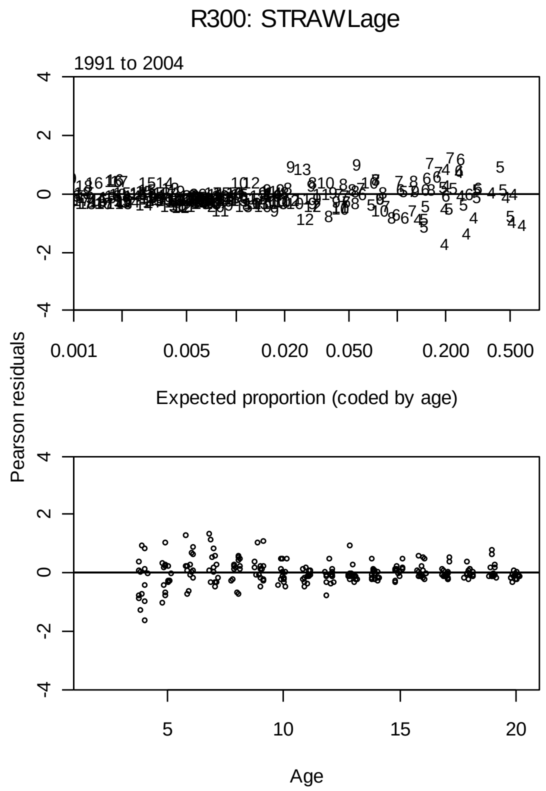


Figure 11: Fit of the SNA 8 R300 and R600 options (left and right panels respectively) to the single trawl catch-at-age data for the years 1991 and 2004.



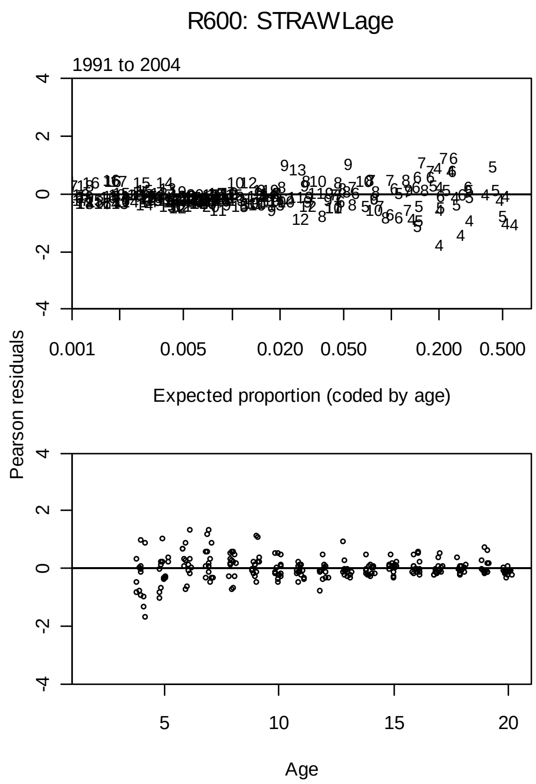


Figure 12: Diagnostic plots of the Pearson residuals from the fit of the R300 and R 600 options (left and right panels respectively) to the single trawl catch-at-age data for 1991 to 2004.

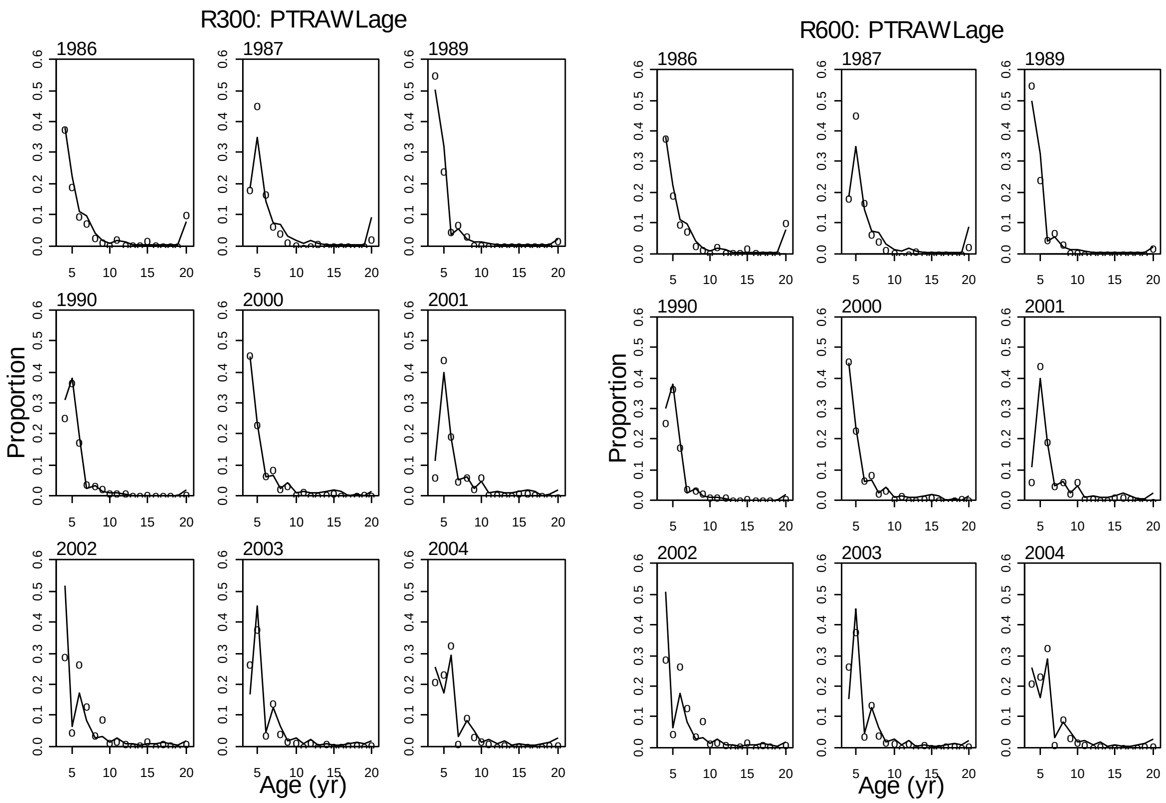


Figure 13: Fit of the R300 and R600 options (left and right panels respectively) to the SNA 8 pair trawl catch-at-age data for 1989 to 2004.

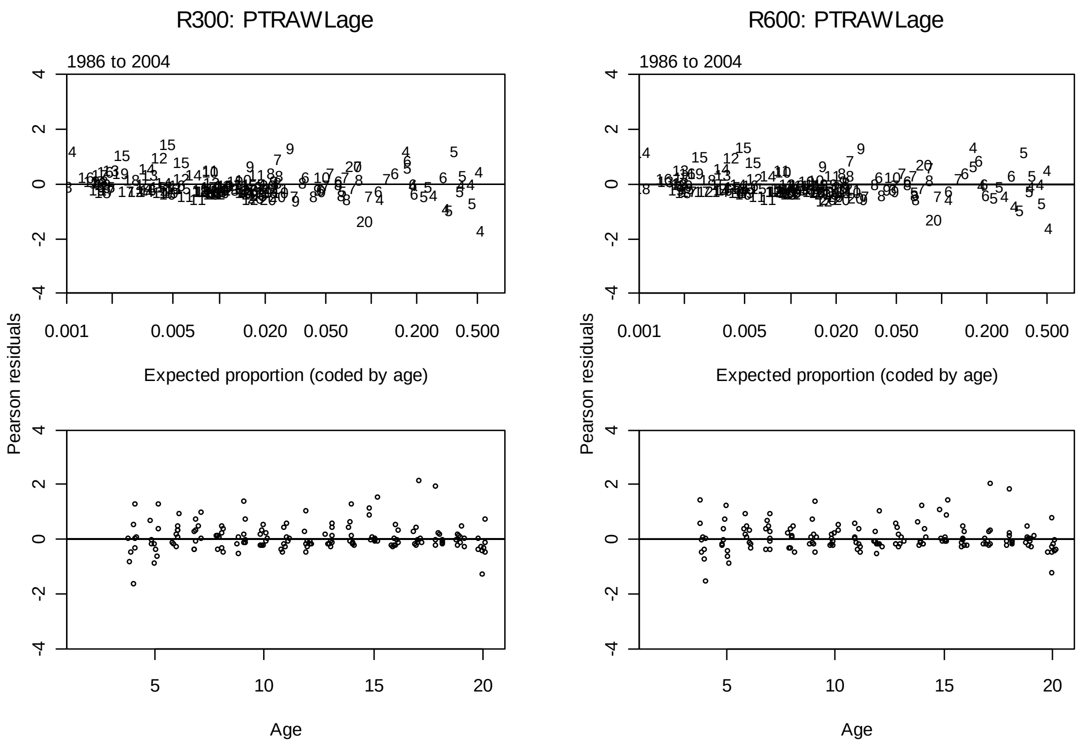


Figure 14: Diagnostic plots of the Pearson residuals from the fit of the R300 and R 600 options (left and right panels respectively) to the pair trawl catch-at-age data for 1989 to 2004.

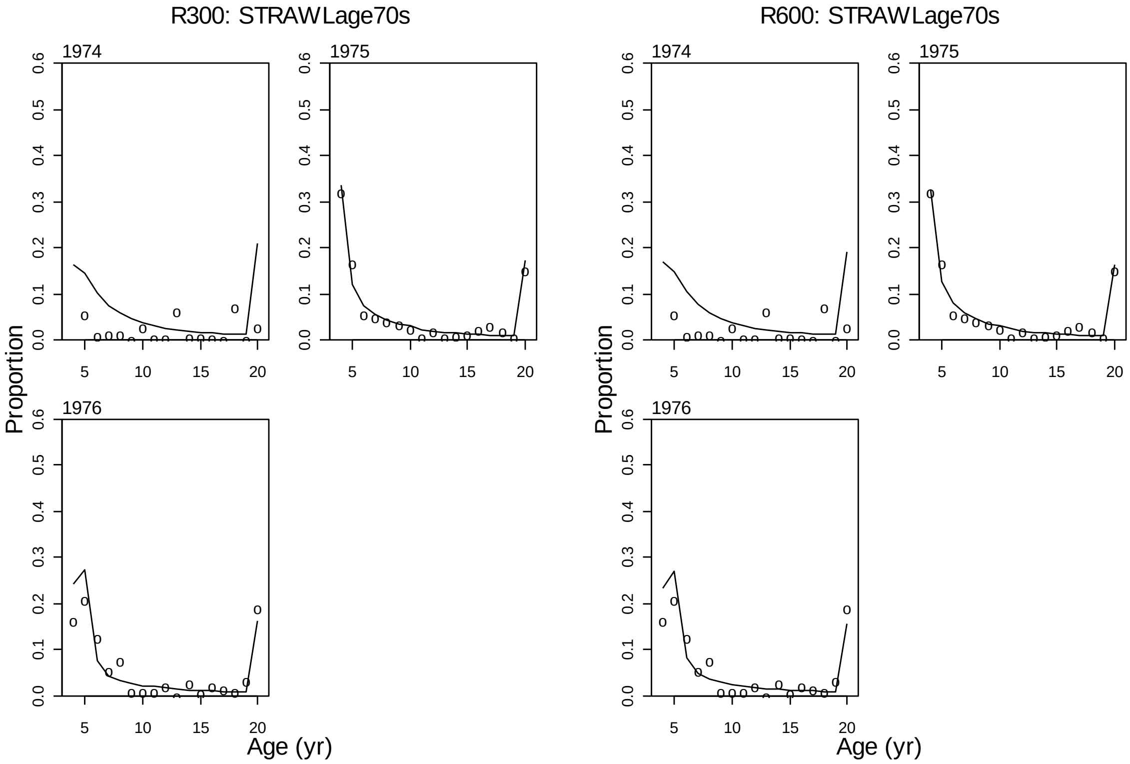


Figure 15: Fit of the R300 and R600 options (left and right panels respectively) to the SNA 8 single trawl catch-at-age data for 1974 to 1976.

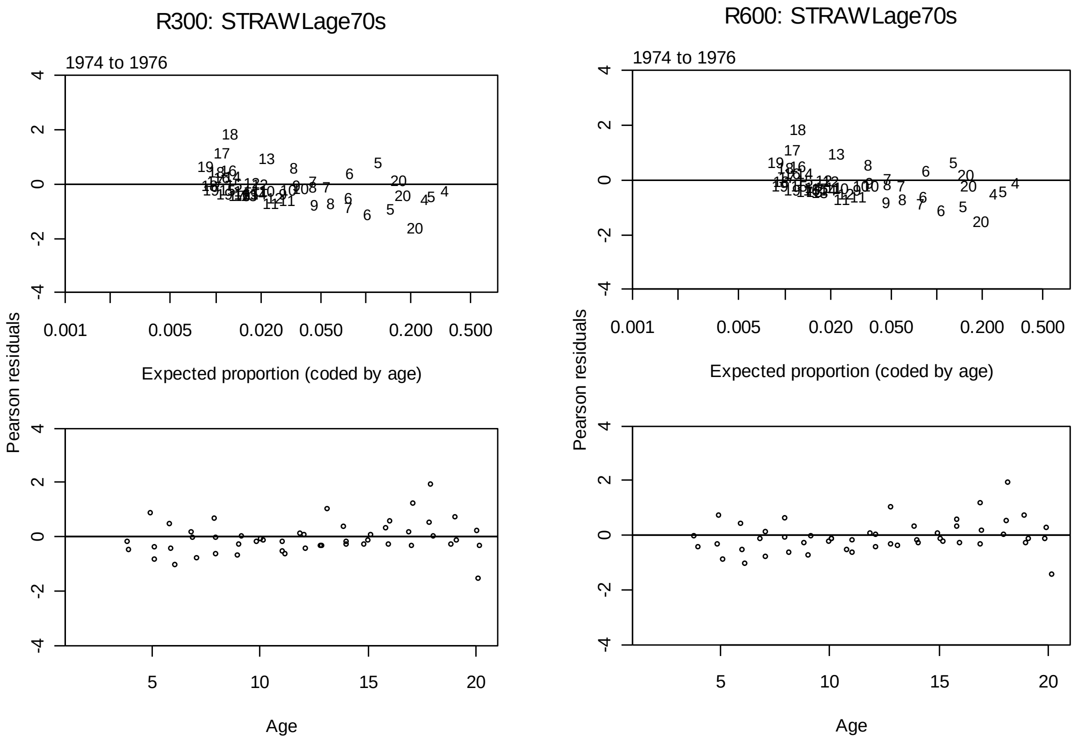


Figure 16: Plots of the Pearson residuals from the fit of the R300 and R 600 options (left and right panels respectively) to the single trawl catch-at-age data for 1974 to 1976.

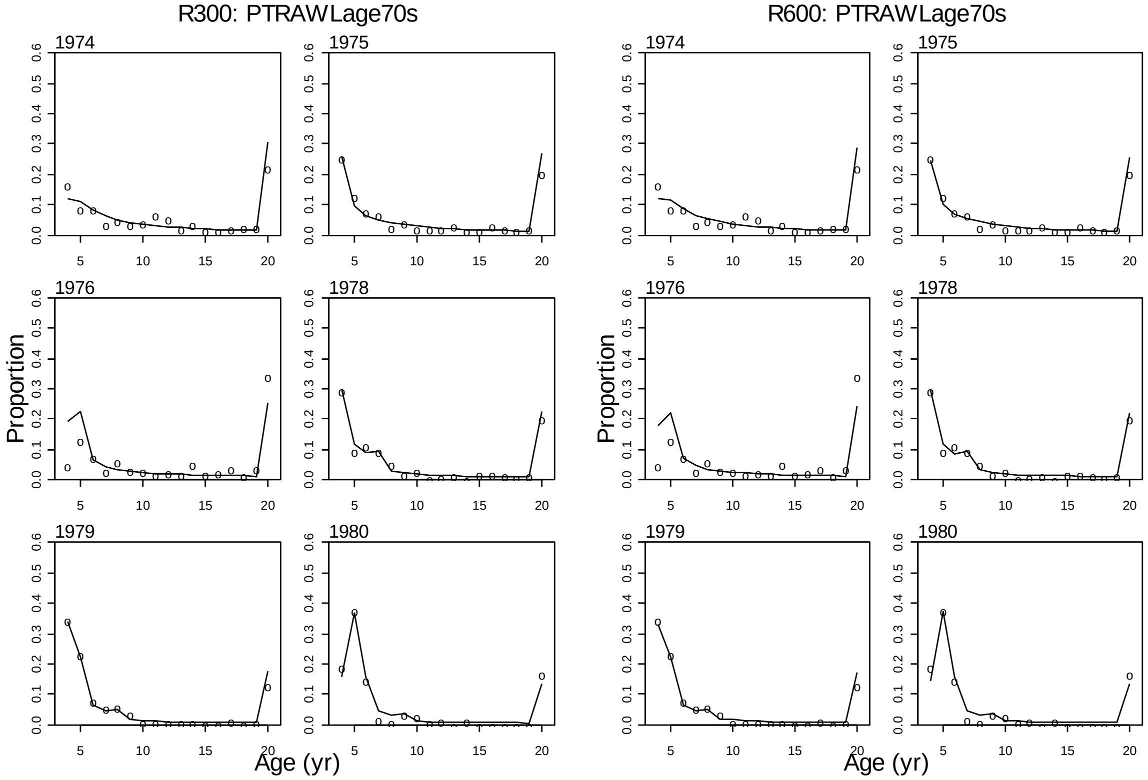


Figure 17: Fit of the R300 and R600 options (left and right panels respectively) to the SNA 8 pair trawl catch-at-age data for 1974 to 1980.

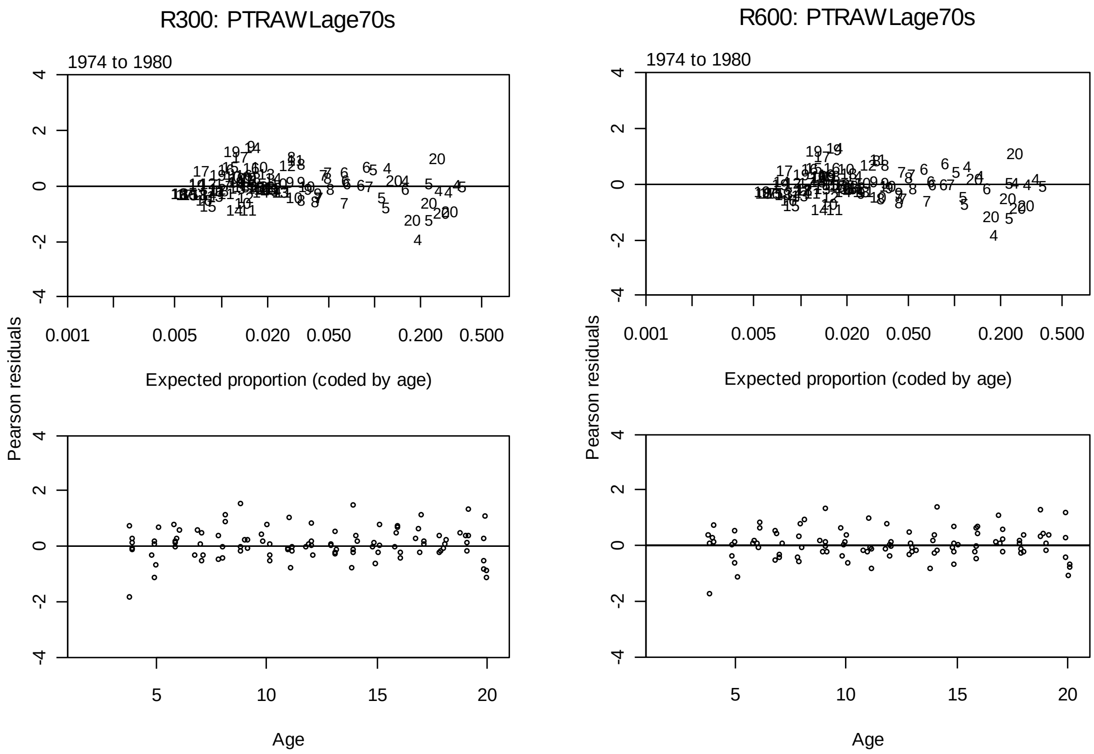


Figure 18: Plots of the Pearson residuals from the fit of the R300 and R 600 options (left and right panels respectively) to the pair trawl catch-at-age data for 1974 to 1980.

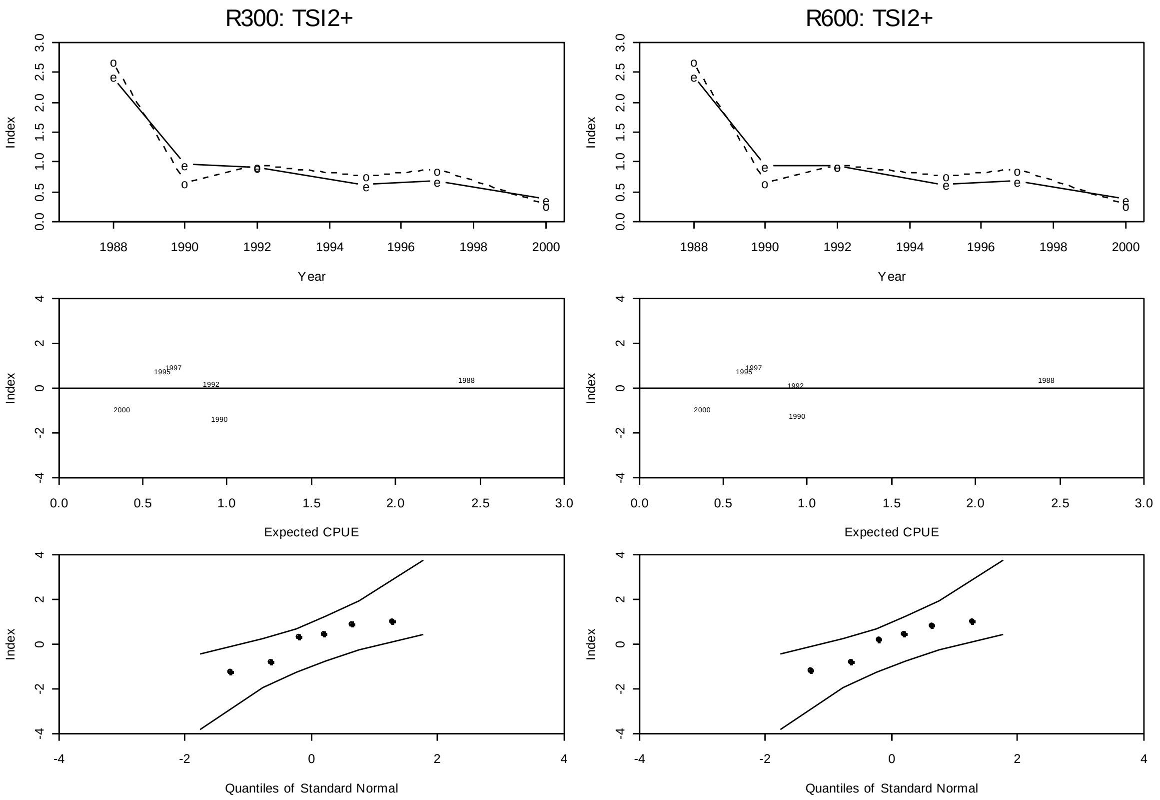


Figure 19: Fit of the R300 and R600 options to the SNA 8 trawl survey indices of 2+ year class strength with QQ-plots.

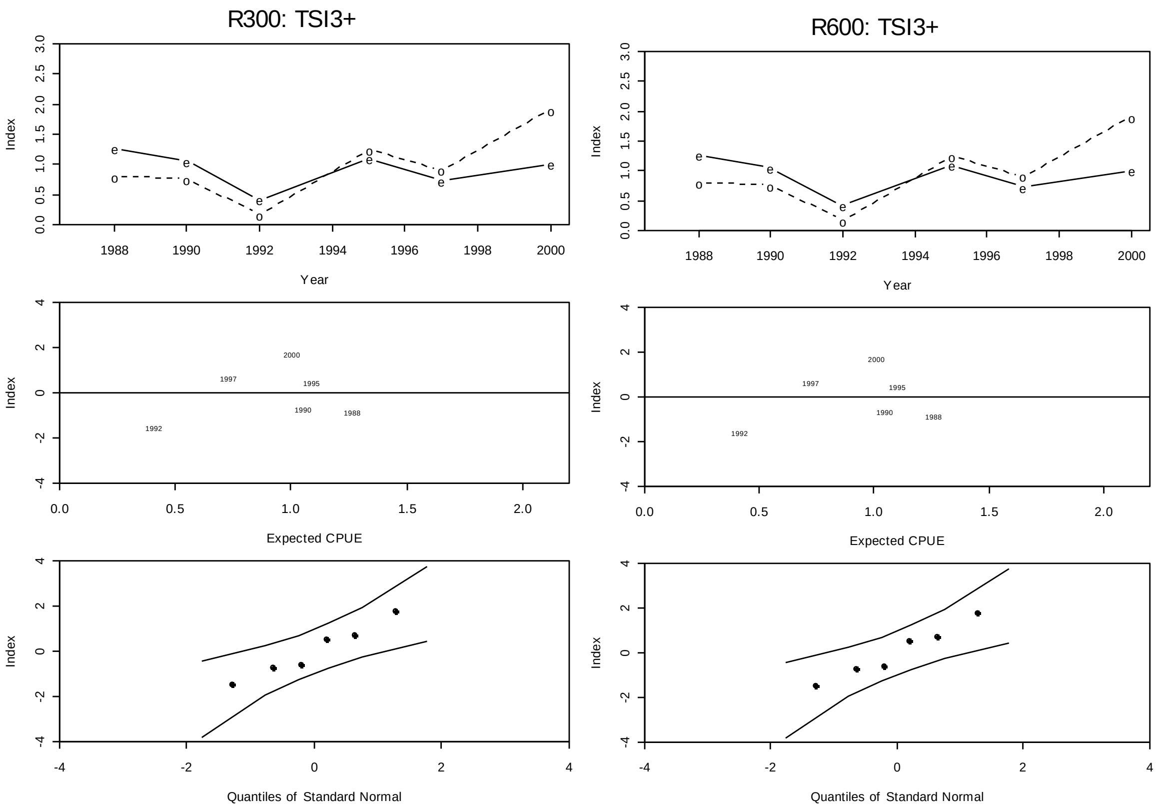


Figure 20: Fit of the R300 and R600 options to the SNA 8 trawl survey indices of 3+ year class strength with QQ-plots.

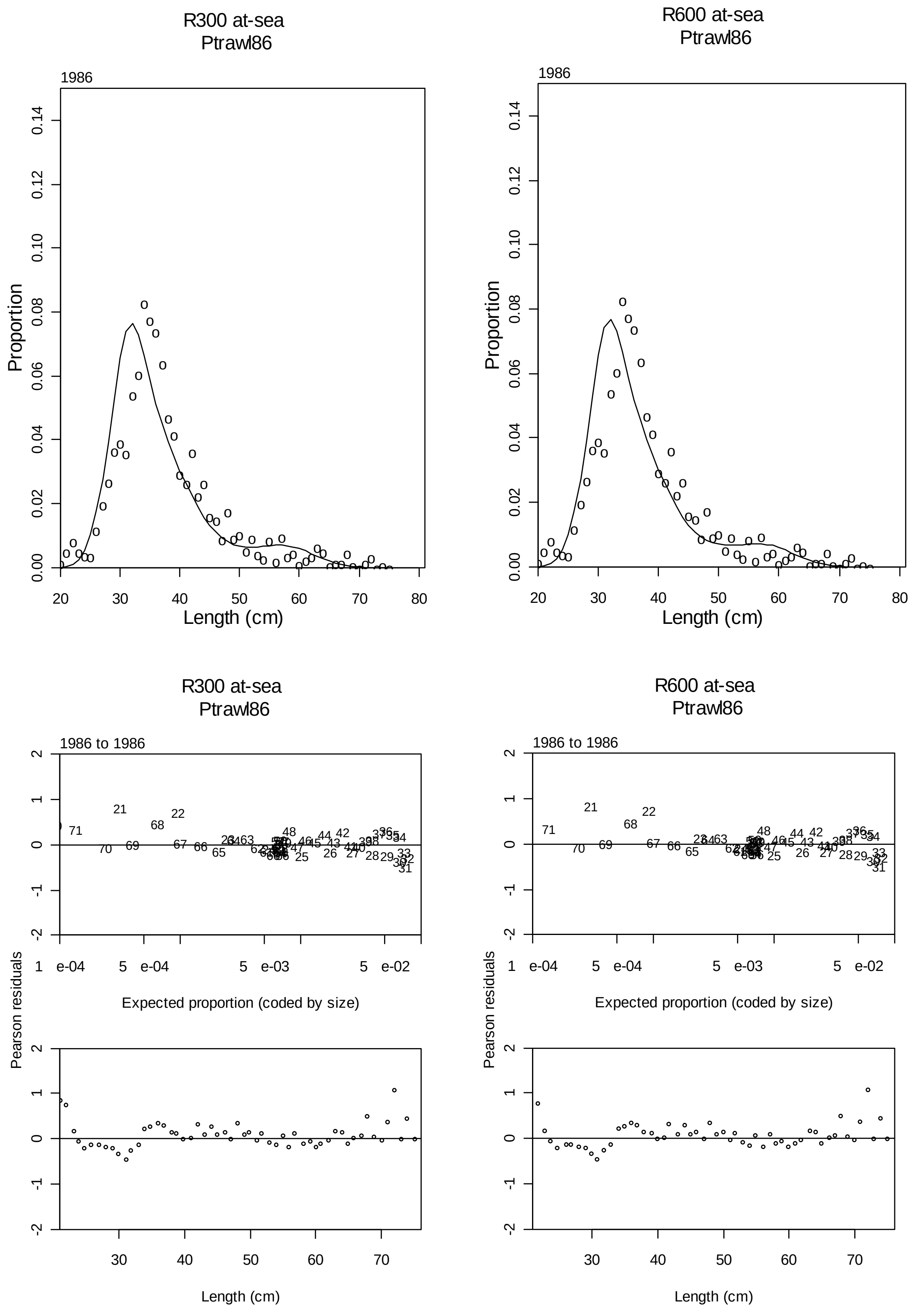


Figure 21: Fit of the R300 and R600 options (left and right panels respectively) to at-sea catch-at-length samples from the SNA 8 pair trawl fishery in 1986, with plots of the Pearson residuals versus predicted proportion and length class (lower panels).

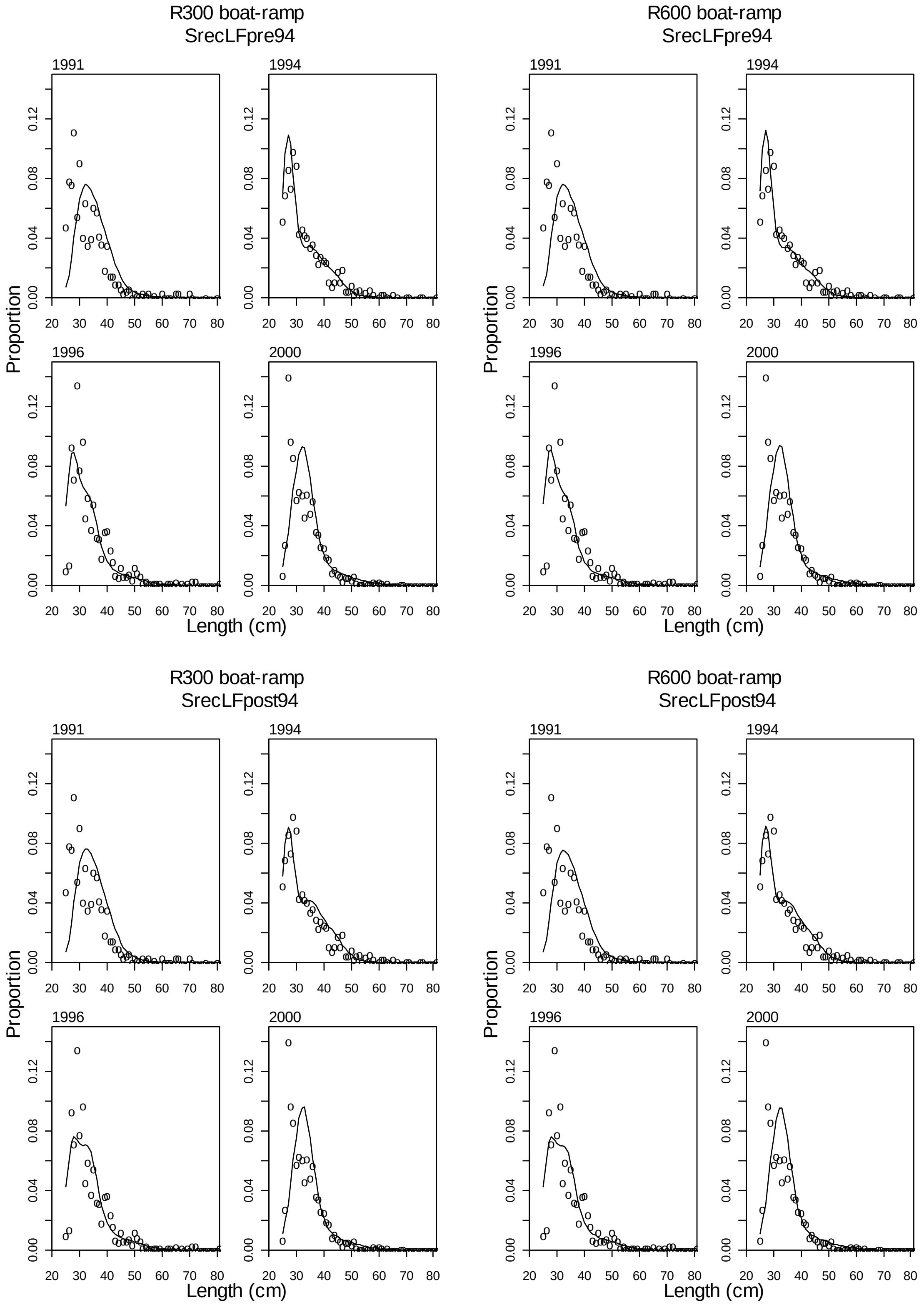


Figure 22: Fit of the R300 and R600 options (left and right panels respectively) to the boat-ramp survey length frequency samples of the SNA 8 recreational fishery for 1991 to 2000, assuming the pre-1994 and post-1994 selectivity-at-length ogives (top and bottom panels respectively).

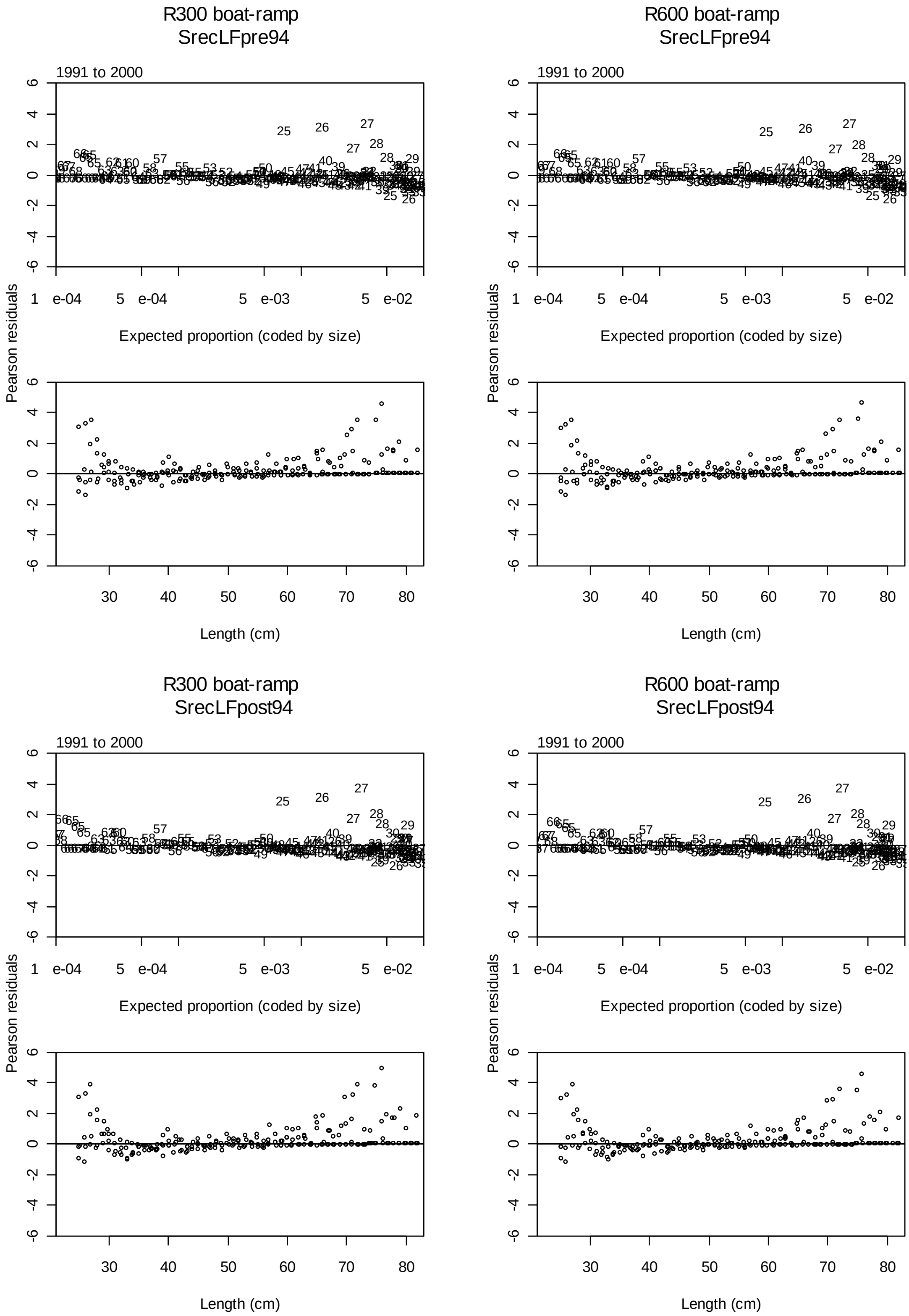


Figure 23: Plots of the Pearson residuals versus predicted proportion and length class from the fit of the R300 and R600 options (left and right panels respectively) to the boat-ramp survey length frequency samples for 1991 to 2000, assuming the pre-1994 and post-1994 selectivity-at-length ogives (top and bottom panels respectively).

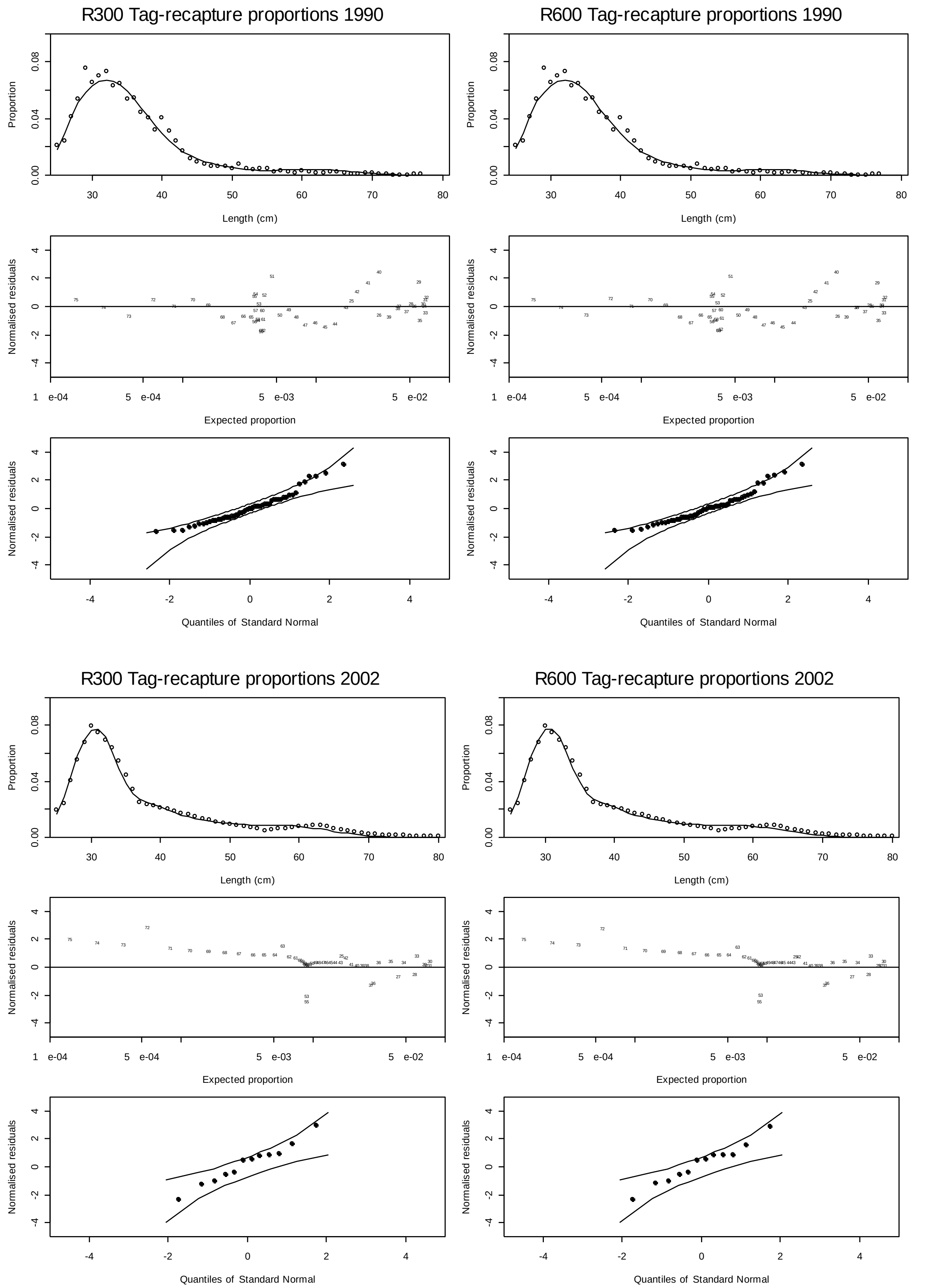


Figure 24: Fit of the R300 and R600 options (left and right panels respectively) to tag-recapture estimates of population length composition in 1990 and 2002 (top and bottom panels respectively) with plots of the standardised residuals versus expected proportion and QQ-norm plots for each set of observations.

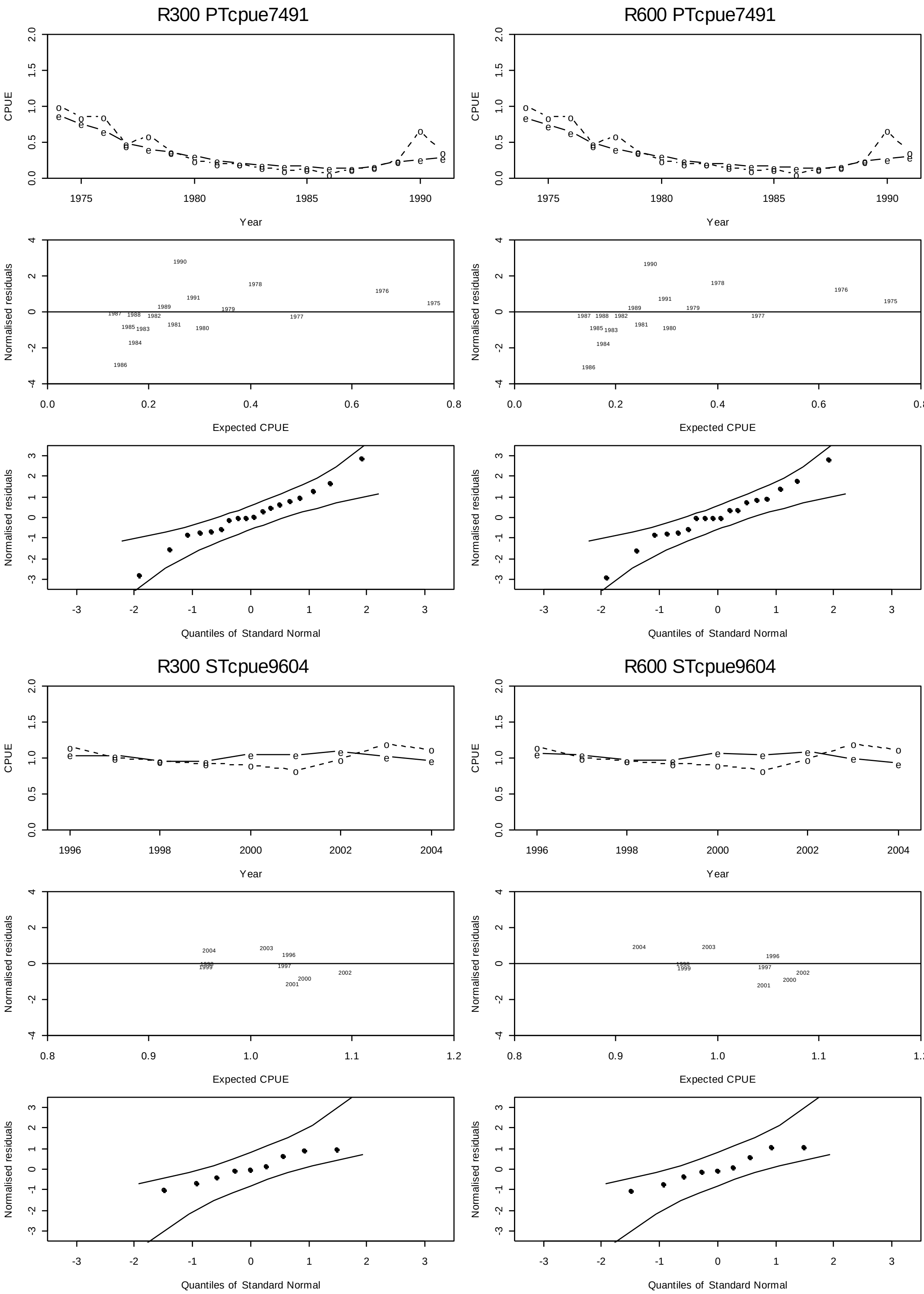


Figure 25: Fit of the R300 and R600 options (left and right panels respectively) to CPUE time series from the SNA 8 pair trawl and single trawl fisheries (top and bottom panels respectively), model is solid line with symbol "e", observed is dashed line with symbol "o", and plots of the standardised residuals versus expected CPUE and QQ-norm plots for each time series.

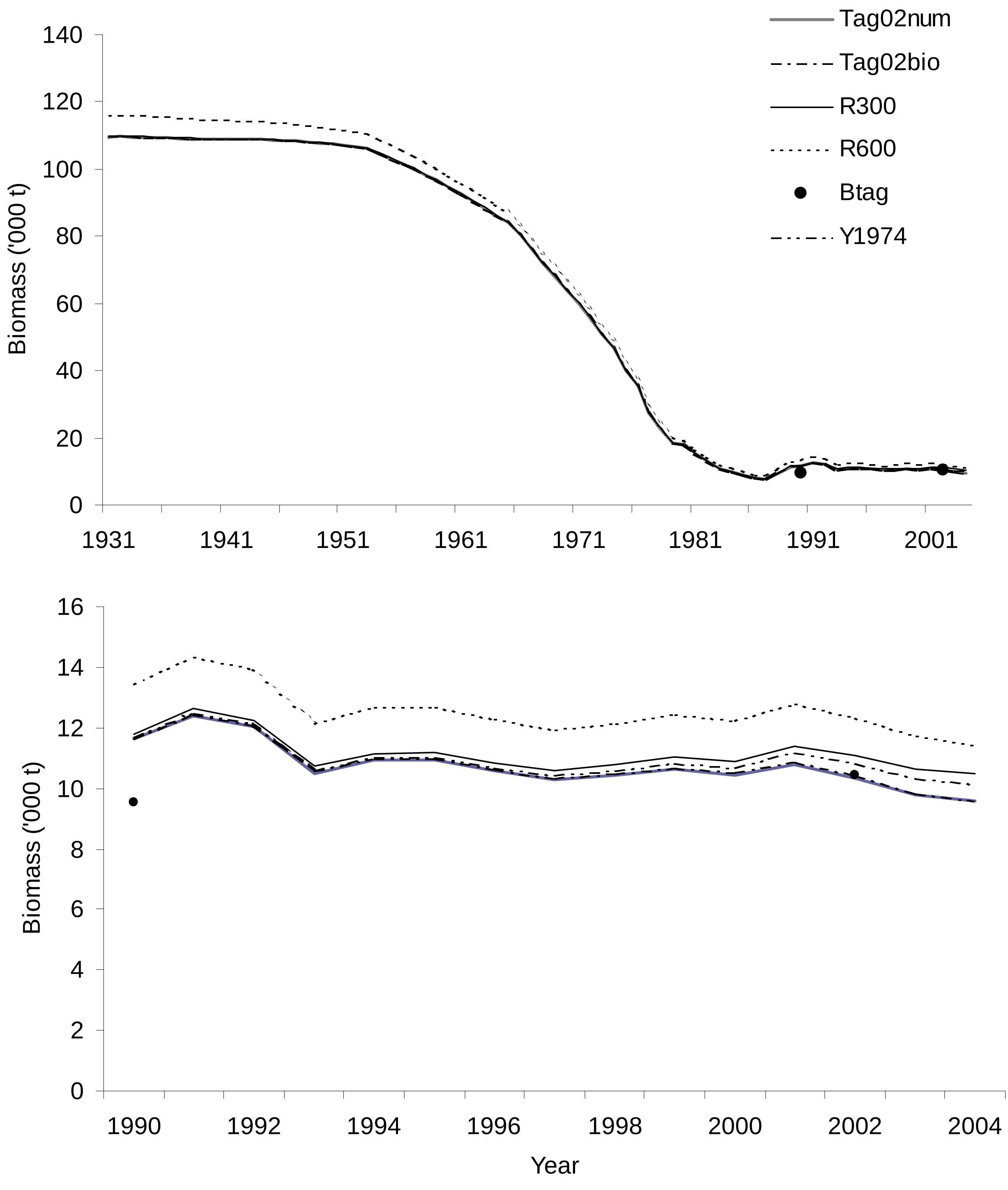


Figure 26: Fit of the R300, R600, Y1974, Tag02bio, and Tag02num options to the tag-recapture estimates of SNA 8 absolute biomass in 1990 and 2002 (Btag), showing predicted biomass for 1931 to 2004 (top panel) and for 1990 to 2004 (bottom panel).

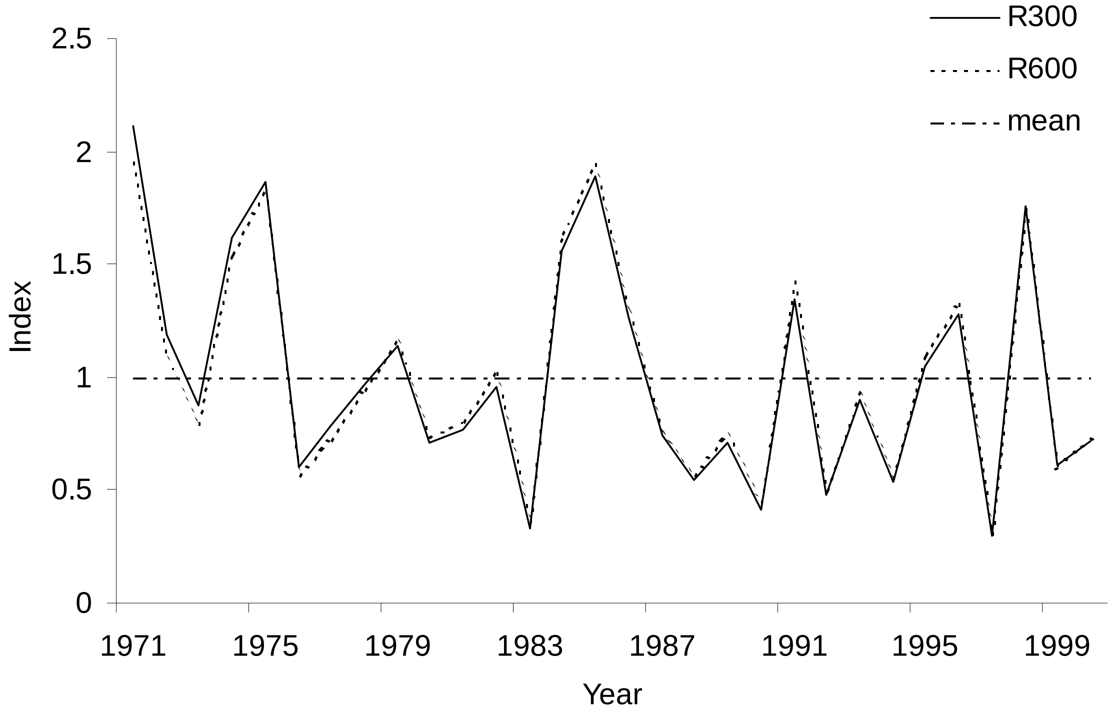


Figure 27: Year class strength estimates for the R300 and R600 options from 1971 to 2000. Mean strength is 1.0 by definition.

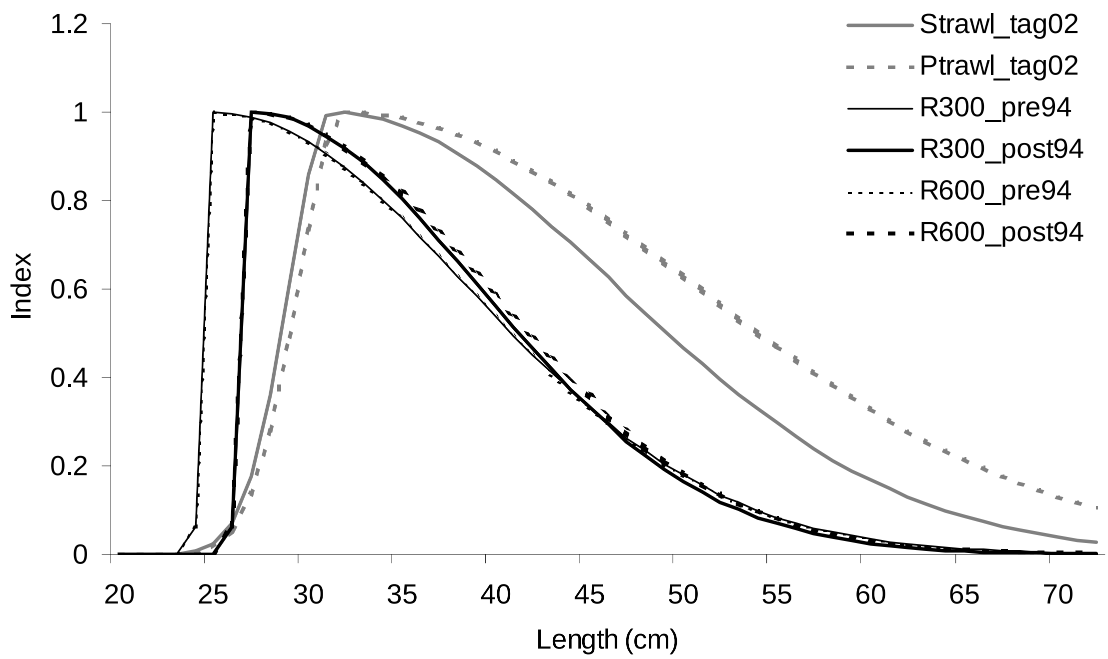


Figure 28: Selectivity-at-length ogives estimated for the R300 and R600 options for SNA 8 recreational fishing for the pre-1994 and post-1994 periods, and for comparison the 2002 tag-recapture estimates for single trawl and pair trawl fishing (Strawl_tag02 and Ptrawl_tag02 respectively).

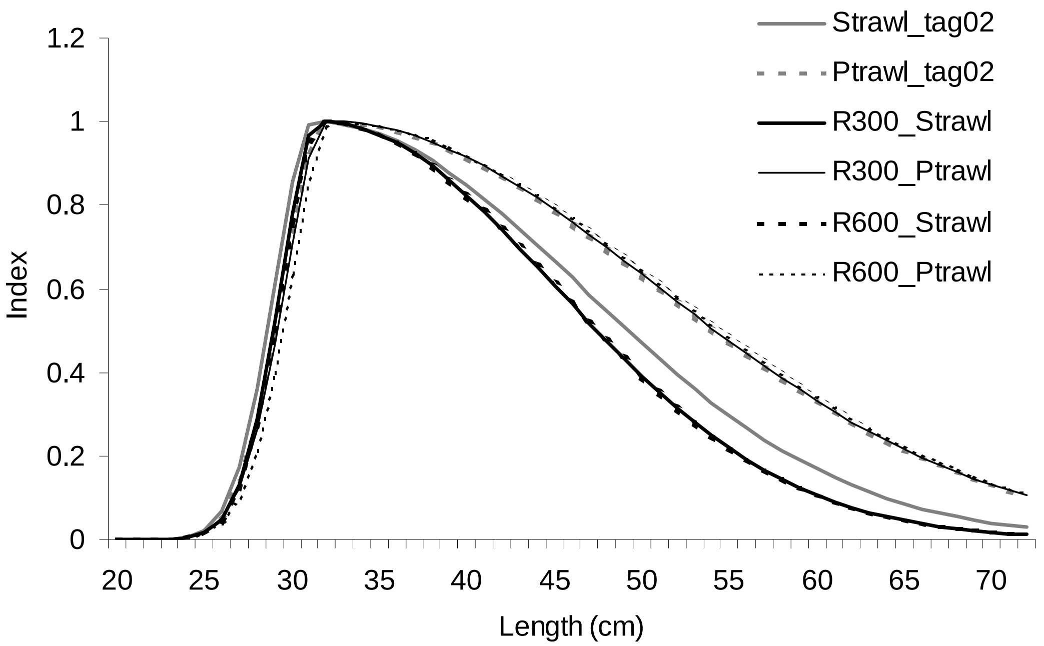


Figure 29: Selectivity-at-length ogives estimated for the R300 and R600 options for the SNA 8 single trawl and pair trawl fishing methods (Strawl and Ptrawl respectively), and for comparison the 2002 tag-recapture estimates for the single trawl and pair trawl fishing methods (Strawl_tag02 and Ptrawl_tag02 respectively).

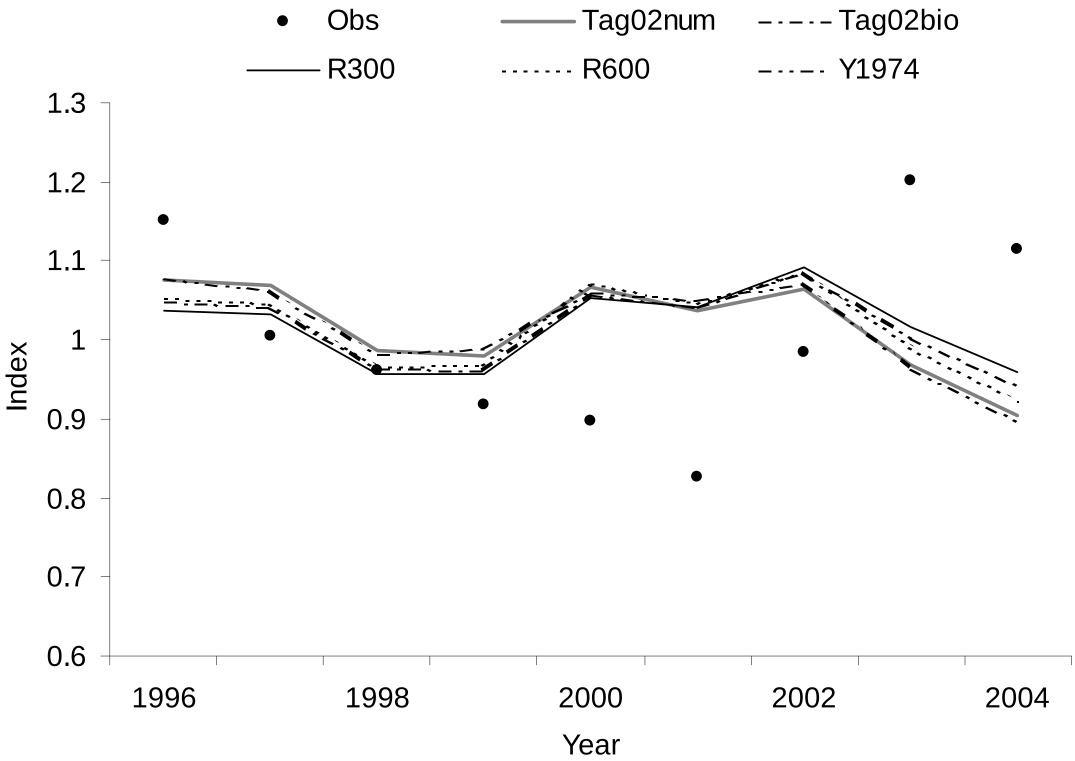


Figure 30: Fit of the R300, R600, Tag02num, Tag02bio and Y1974 options to the SNA 8 single trawl CPUE indices (Obs) from 1996 to 2004. Note y-axis scale minimum is not zero.

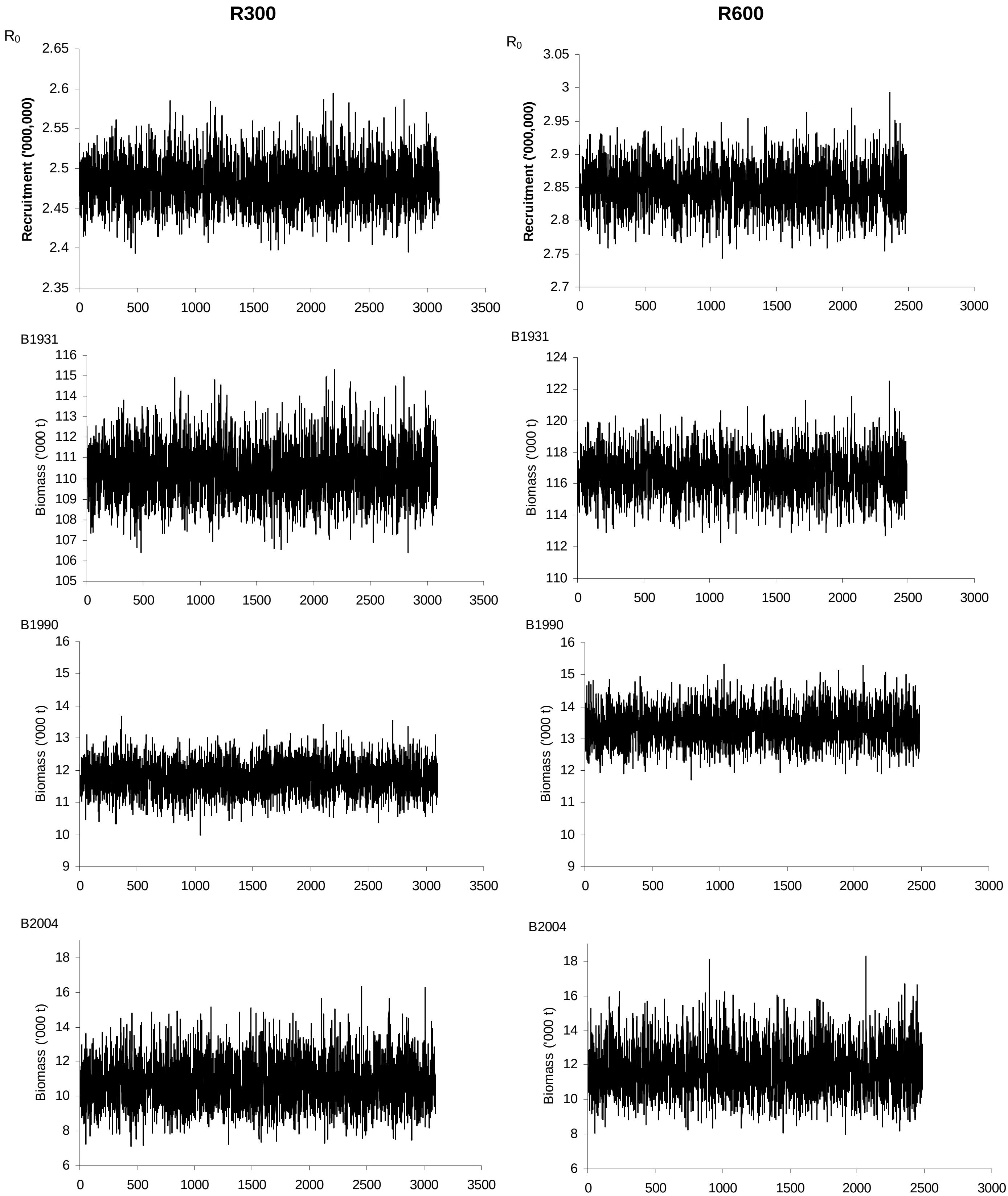


Figure 31: Traces of MCMC chains for the R300 and R600 options (left and right panels respectively) for the parameters: mean recruitment (R_0), unfished equilibrium biomass ($B_{1931} = B_0$), and biomass in 1990 and 2004 (B1990 and B2004 respectively) drawn from the Bayesian posterior samples.

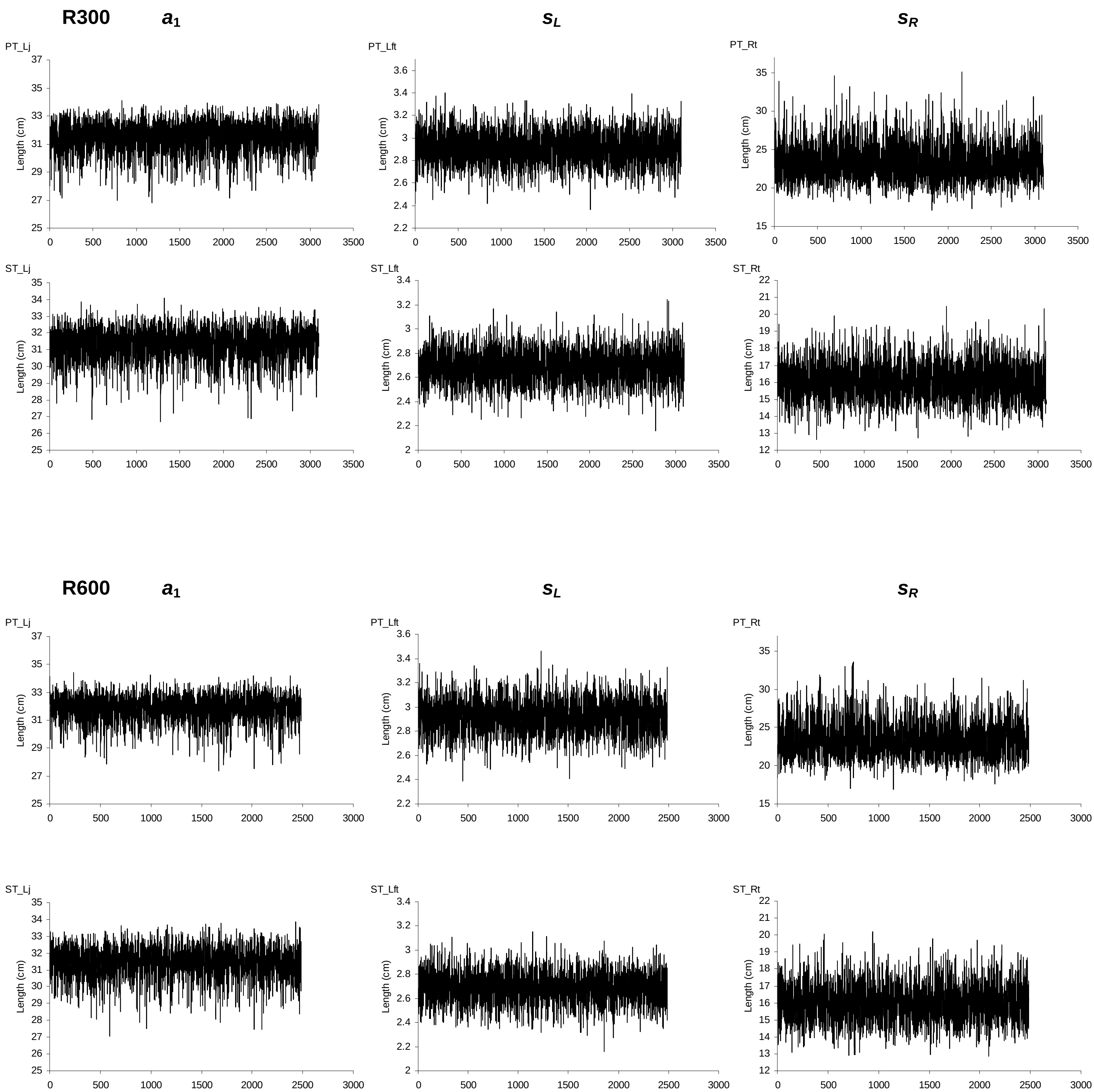


Figure 32: Traces of the MCMC chains for selectivity-at-length parameters: a_1 (left column), s_L (middle column), and s_R (right column); for the R300 (rows 1 and 2) and R600 (rows 3 and 4) options for: pair trawl (rows 1 and 3) and single trawl (rows 2 and 4).

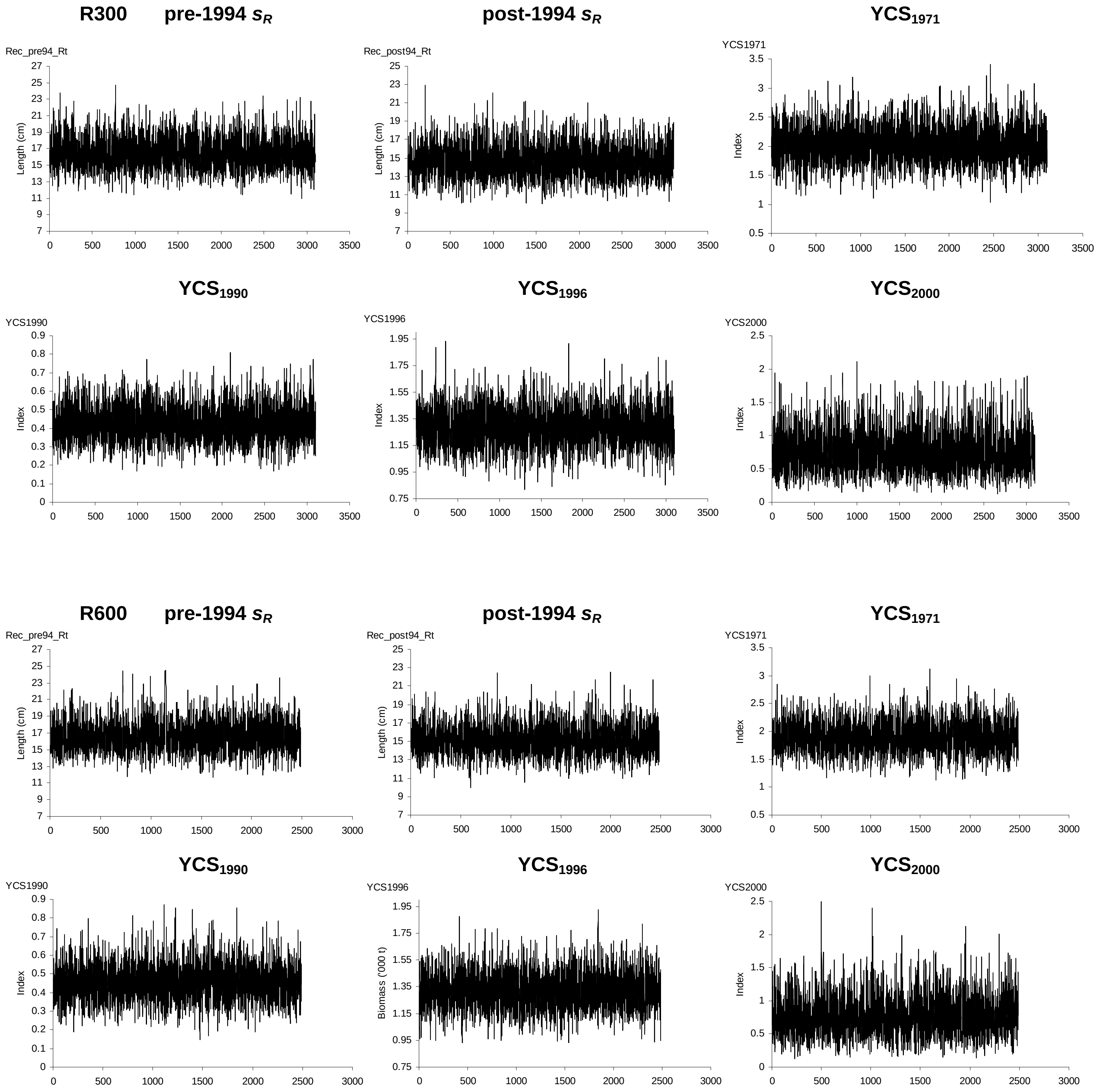


Figure 33: Traces of the MCMC chains for selectivity-at-length parameter s_R for the SNA 8 recreational fishing method before and after 1994 (pre-1994 s_R and post-1994 s_R respectively), and the year class strength parameters for 1971, 1990, 1996 and 2000 (YCS_{1971}, YCS_{1990}, YCS_{1996}, YCS_{2000} respectively) for the R300 (rows 1 and 2) and R600 options (rows 3 and 4).

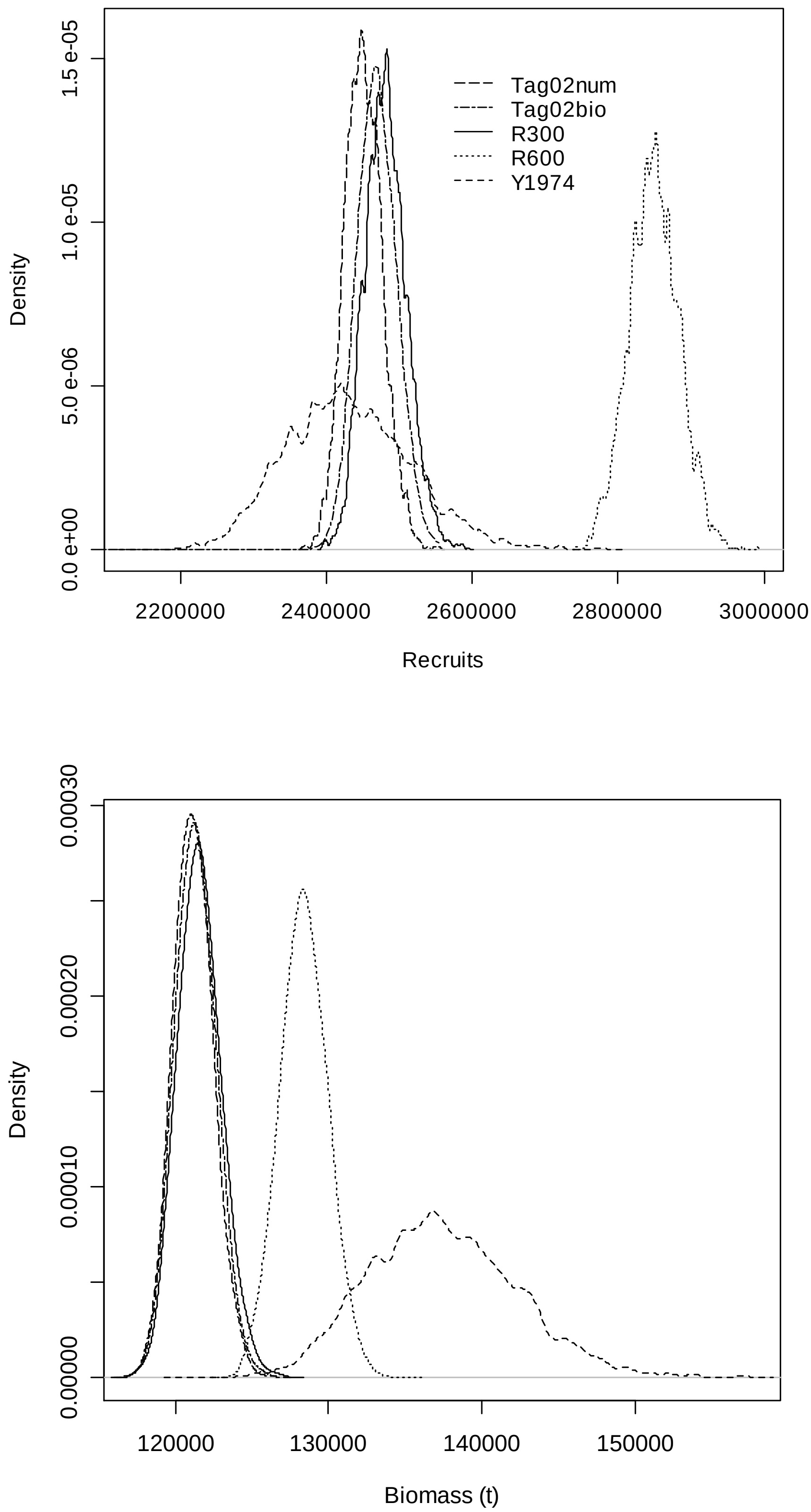


Figure 34: Marginal posterior density functions for mean recruitment (R_0) and unfished biomass (B_0), (top and bottom panels respectively) estimated for the range of SNA 8 model options.

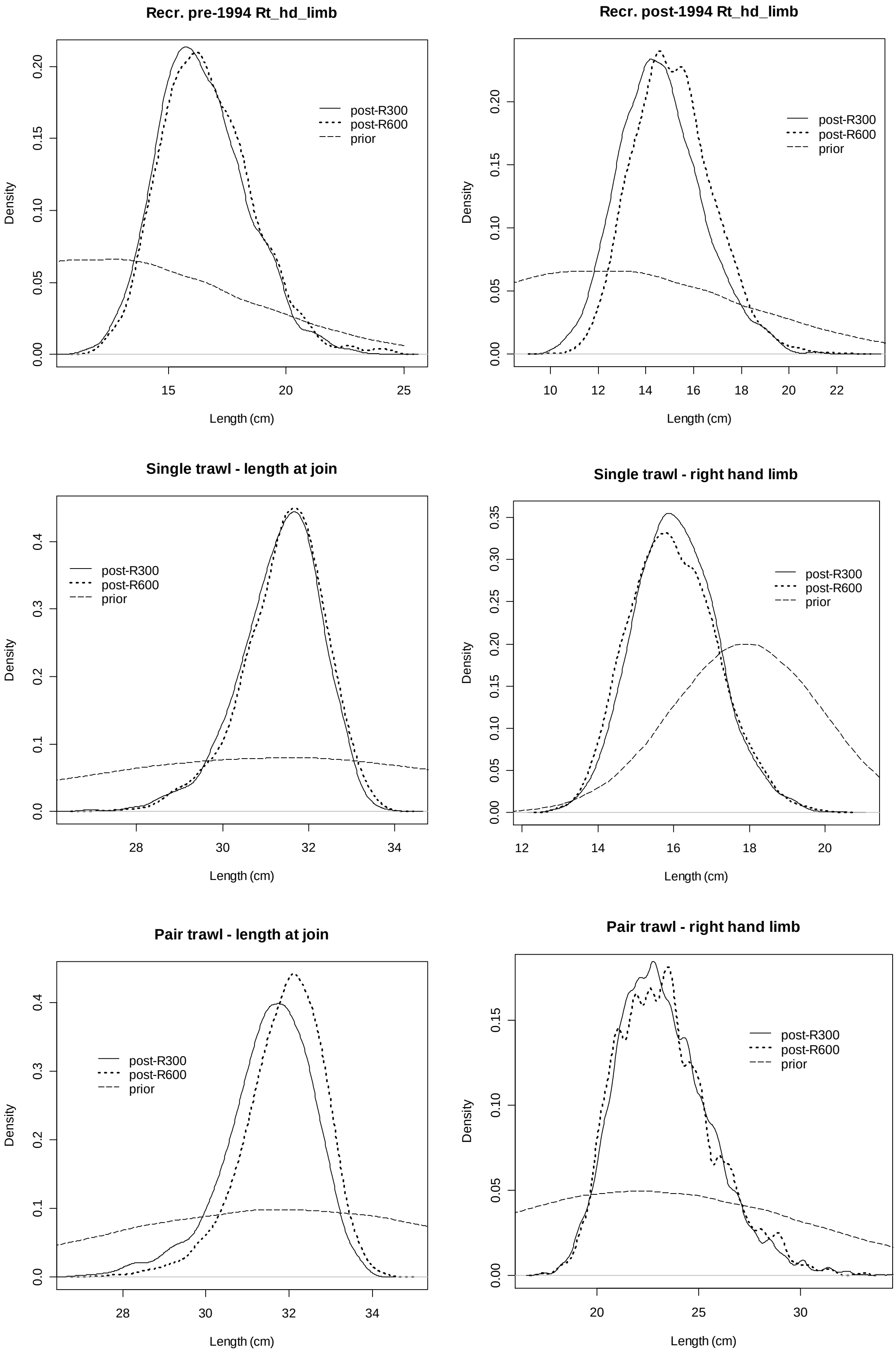


Figure 35: Marginal posterior density functions for selectivity parameter estimates with priors for the R300 and R600 options for recreational method right-hand limb pre- and post-1994 (top panels), pair trawl length at join and right-hand limb (middle panels), and single trawl length at join and right-hand limb (bottom panels).

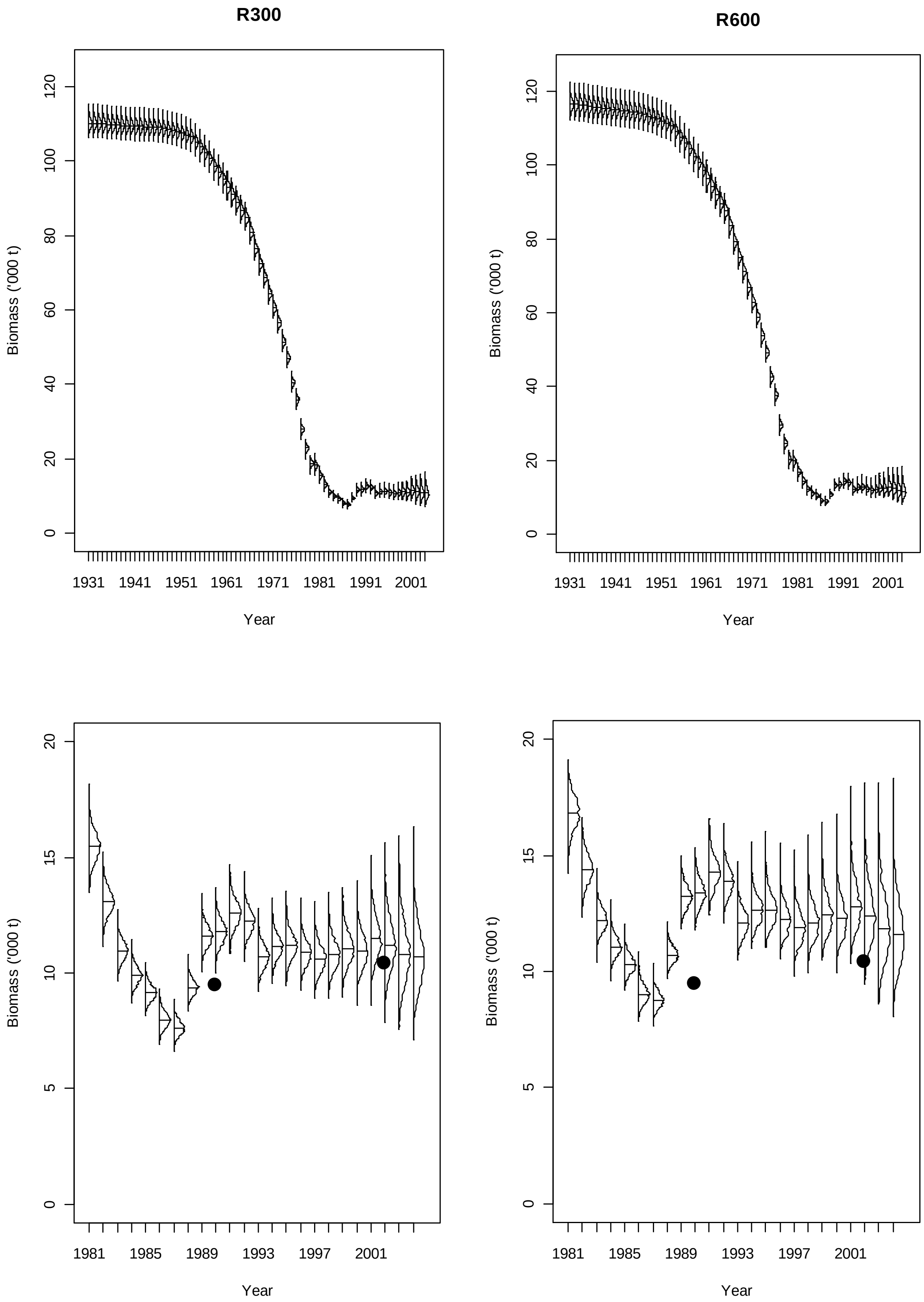


Figure 36: Marginal posterior density functions of annual biomass for SNA 8 options R300 and R600 (left and right panels respectively) for 1931–2004 (top panels), and for 1981–2004 (bottom panels) showing the tag-recapture estimates of absolute biomass (solid circles).

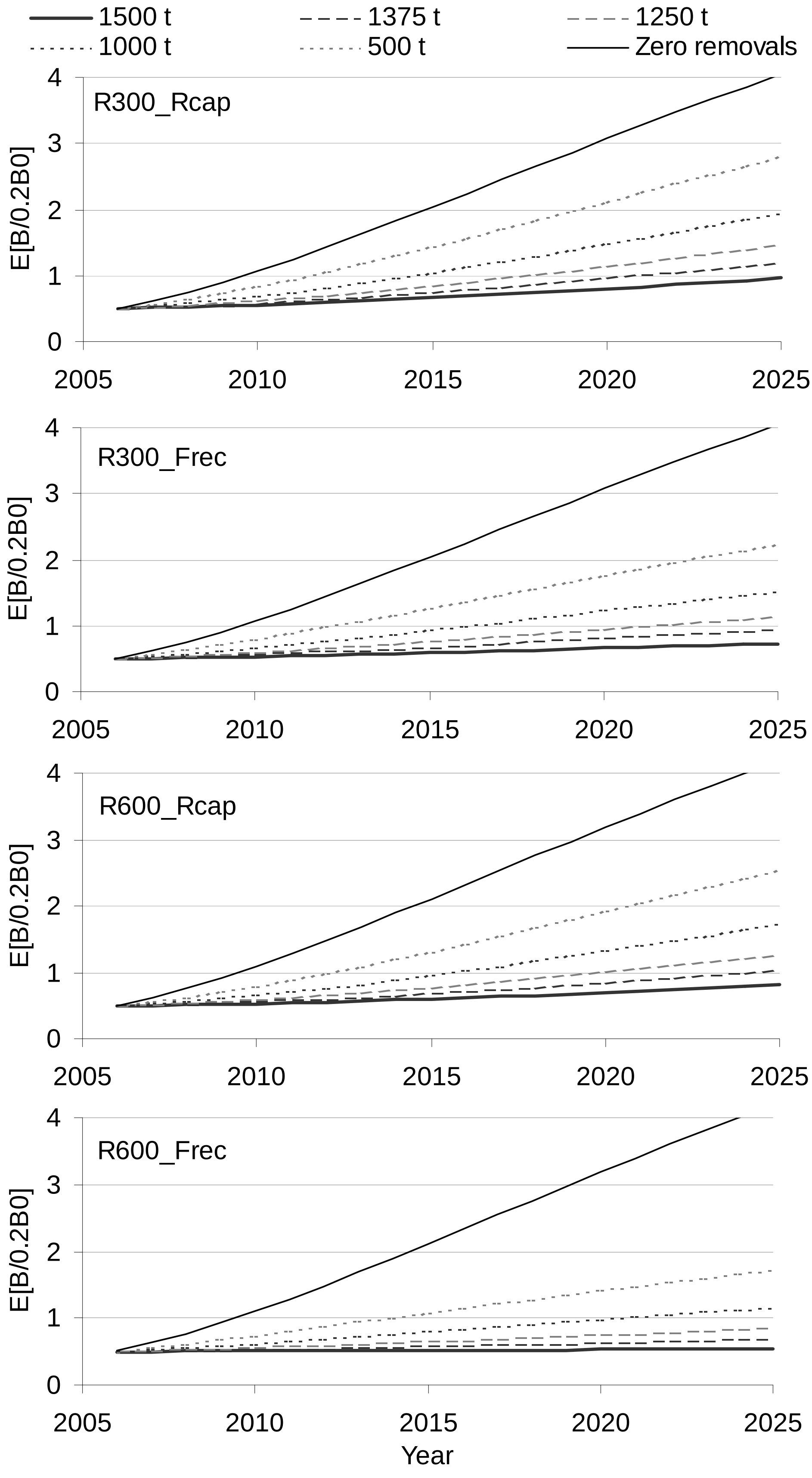


Figure 37: Expected ratio of biomass to 0.2B_0 forecast to 2025 for the R300 and R600 options under two alternative options for recreational catch: Rcap, constant annual catch of 300 or 600 t respectively, and Frec, constant annual exploitation rate at the MPD level estimated in 2004. For each model option future TACC levels of 500, 1000, 1250, 1375 and 1500 t are plotted and compared to zero removals from the population (light solid line).

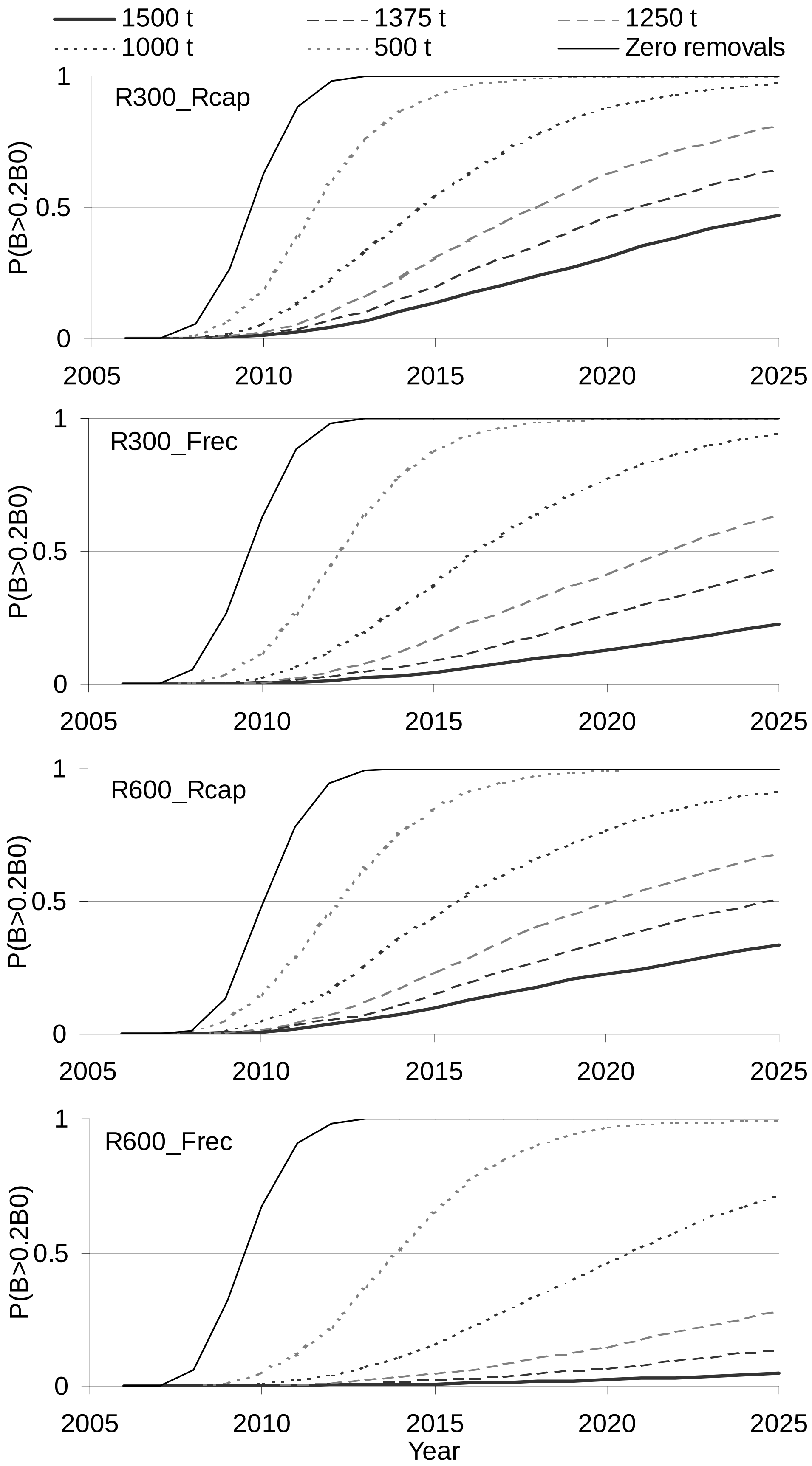


Figure 38: The probability of predicted biomass exceeding $0.2B_0$) by 2025 for the R300 and R600 options under two alternative options for recreational catch: Rcap, constant annual catch of 300 or 600 t respectively, and Frec, constant annual exploitation rate at the MPD level estimated in 2004. For each model option future TACC levels of 500, 1000, 1250, 1375 and 1500 t are plotted and compared to zero removals from the population (light solid line).

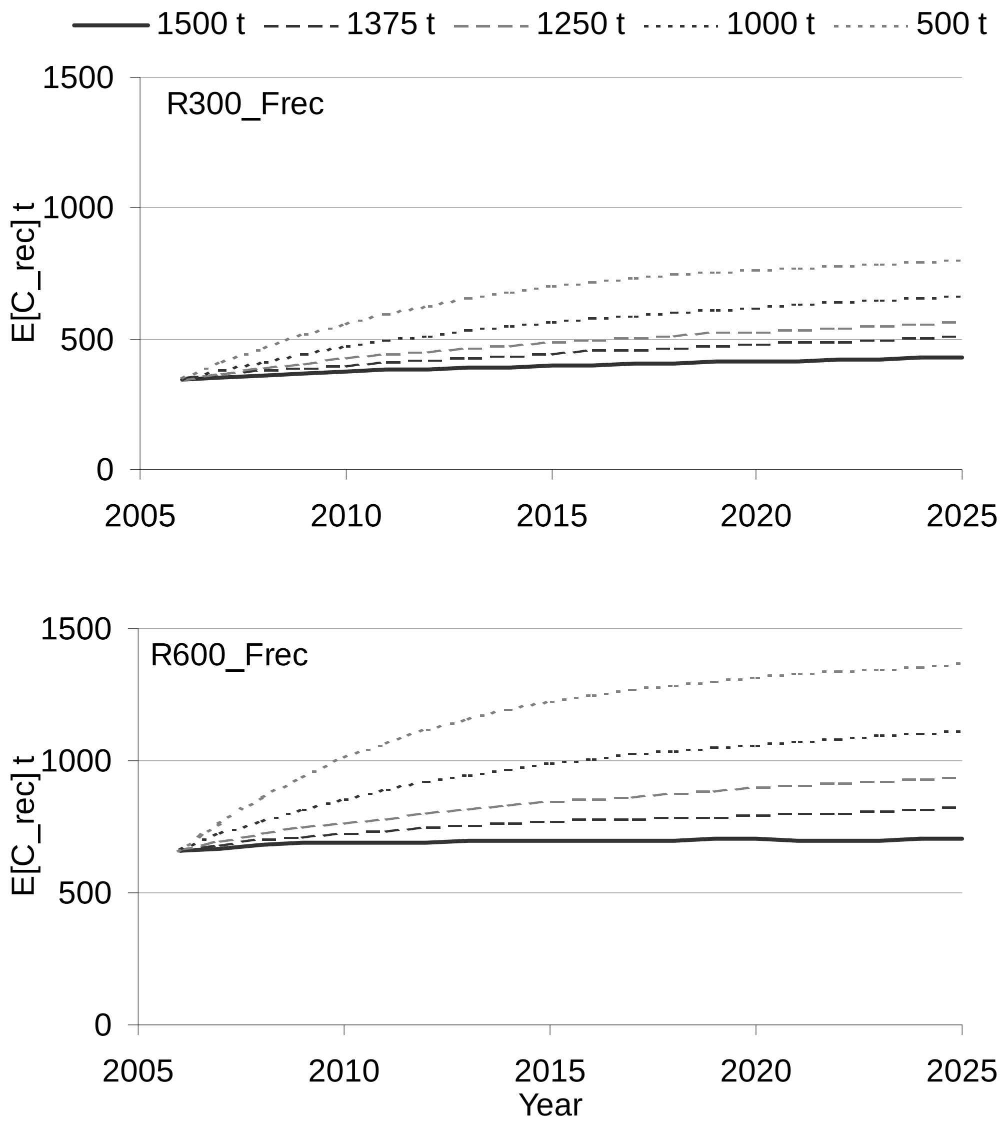


Figure 39: The expected annual recreational catch (E[C_rec] t) forecast to 2025 for the R300 and R600 options under constant annual recreational exploitation rate equal to the 2004 MPD . For each model option future TACC levels of 500, 1000, 1250, 1375 and 1500 t are plotted.

9. Appendix 1: Full model (all parameters and interactions) GLM regression using SNA 8 single bottom trawl data (catch nm -1tow -1).

CPUE = catch $nm^{-1}tow^{-1}$
log(CPUE)~vkey+month+(year+target+stat)^2,

Results of full model with 2nd level interaction terms
Top 20 vessels

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			21499	31890			
Vkey	19	3868	21480	28022	181.1287	< 2.2e-16	***
Month	11	1775	21469	26247	143.5313	< 2.2e-16	***
Year	8	198	21461	26050	21.9787	< 2.2e-16	***
Target	1	1136	21460	24914	1011.0040	< 2.2e-16	***
Stat	6	292	21454	24622	43.2914	< 2.2e-16	***
year:target	8	39	21446	24582	4.3617	2.824e-05	***
year:stat	47	508	21399	24075	9.6127	< 2.2e-16	***
target:stat	6	29	21393	24045	4.3337	0.0002237	***

Top 12 vessels

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			16358	24512.1			
Vkey	11	3107.8	16347	21404.2	253.6592	< 2.2e-16	***
Month	11	1548.2	16336	19856.0	126.3638	< 2.2e-16	***
Year	8	183.4	16328	19672.6	20.5829	< 2.2e-16	***
Target	1	792.8	16327	18879.9	711.7426	< 2.2e-16	***
Stat	6	246.2	16321	18633.7	36.8387	< 2.2e-16	***
year:target	8	65.1	16313	18568.6	7.3007	9.98e-10	***
year:stat	43	434.0	16270	18134.6	9.0619	< 2.2e-16	***
target:stat	5	18.2	16265	18116.3	3.2760	0.005855	**

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ‘ 1

10. Appendix 2: Predictor variable coefficients from stepwise GLM regression using SNA 8 single bottom trawl data (catch nm $^{-1}$tow $^{-1}$).

STEPWISE REGRESSION
log(CPUE)~year+vkey+month+stat
Top 20 vessels

Start: AIC= 64835.85
log(CPUE) ~ year + month + vkey + stat

	Df	Deviance	AIC
<none>		25573	64836
- stat	6	26050	65221
- month	11	26993	65976
- vkey	19	27768	66569

Result: no terms dropped

Top 12 vessels
Start: AIC= 49194.22
log(CPUE) ~ year + vkey + month + stat

	Df	Deviance	AIC
<none>		19287	49194
- stat	6	19673	49506

- month	11	20504	50173
- vkey	11	20696	50326

Result: no terms dropped

11. Appendix 3: Mean weight-at-age from the SNA 8 age-length samples collected from 1975 to 1979.

11.1 Sampling design

A two-stage random sampling design was used for each landing. Firstly, bins were randomly selected from each landing. Secondly, a fixed random sample of fish (usually n = 10) was selected from each sample bin even though the number of fish in bins varied widely. In a few instances the landing was also stratified and strata within the landing were sampled. Since ages of fish in the same stratum were typically not correlated, this aspect of the design was ignored. All selected fish were dissected for an otolith sample and measured for fork length. The total number of all fish in each bin was recorded, and the total number of bins in each landing. All otoliths were read and ages recorded.

11.2 Mean weight-at-age

A mean weight-at-age was calculated for each year that samples were collected. Firstly, an estimate was calculated for each method-season stratum. This estimate took account of the sampling design used, and, hence, accounted for the relative sample weight for each bin within a landing, and the relative size of landings. The following approach derives a weighted mean weight-at-age for a method-season stratum.

Weight of a fish of length l is al^b. Weight of the n_{kmj} fish of age j in bin m, in landing k is

$$\sum_i al_{kmji}^b$$

The estimated weight of these n_{kmj} fish is

$$\frac{B_{km}}{b_{km}} \sum_i al_{kmji}^b$$

where B_{km} is the number of fish in bin m, in landing k, and b_{km} is the number of fish sampled from bin m, in landing k. The estimated number of fish of age j in bin m, in landing k is

$$\frac{B_{km}}{b_{km}} n_{kmj}$$

Hence the estimated weight and number of fish of age j in landing k are

$$\frac{M_k}{m_k} \sum_{m=1}^{m_k} \left(\frac{B_{km}}{b_{km}} \sum_i al_{kmji}^b \right) \text{ and } \frac{M_k}{m_k} \sum_{m=1}^{m_k} \frac{B_{km}}{b_{km}} n_{kmj}$$

where M_k is the total number of bins in landing k and m_k is the number of bins sampled. Summing over all the landings sampled, the estimated weight and number of fish of age j in the landings sampled are

$$\sum_k \left[\frac{M_k}{m_k} \sum_{m=1}^{m_k} \left(\frac{B_{km}}{b_{km}} \sum_i al_{kmji}^b \right) \right] \text{ and } \sum_k \frac{M_k}{m_k} \left[\sum_{m=1}^{m_k} \frac{B_{km}}{b_{km}} n_{kmj} \right]$$

Hence the estimated mean weight of fish of age j is

$$\hat{\bar{w}}_j = \frac{\sum_k \left[\frac{M_k}{m_k} \sum_{m=1}^{m_k} \left(\frac{B_{km}}{b_{km}} \sum_i al_{kmji}^b \right) \right]}{\sum_k \frac{M_k}{m_k} \left[\sum_{m=1}^{m_k} \frac{B_{km}}{b_{km}} n_{kmj} \right]}$$

Ages that are rare will not occur in the samples from some landings. This will simply result in zero terms in the summations over k.