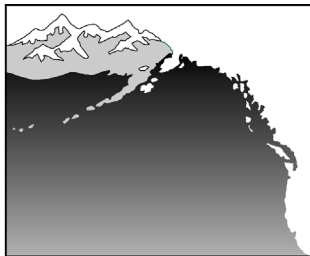# Stock Assessment of the Campbell Island Rise Population of Southern Blue Whiting (*Micromesistius australis*) for the 2000-01 Fishing Season

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Acknowledgments

Key Words

Stock Assessment of the Campbell Island Rise Population of Southern Blue Whiting (*Micromesistius australis*) for the 2000-01 Fishing Season

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1. Executive Summary

A Bayesian age-structured model was used to provide an assessment of the Campbell Island Rise stock of southern blue whiting (*Micromesistius australis*) in New Zealand waters. The New Zealand fishery on southern blue whiting is confined to mid-water trawling during the spawning season (August–September), when the fish aggregate.

The model uses year-specific weight-at-age data with sexes combined. Recruitment is assumed to follow a Beverton–Holt curve with high (0.95) steepness and a recruitment standard deviation of 1.0; recruitment deviations are estimated for each year and for each age of the initial age structure. Left-hand selectivity is estimated using a two-parameter function, and is assumed to be constant over all years of the fishery. Survey q values are estimated separately for 1, 2, 3, and 4+ year olds.

The model provides good fits to the fishery data, which consist of catch-at-age proportions from 1979 to 2000, and acoustic surveys of 1, 2, 3 and 4+ year-old fish in 1993–95, 1998, and 2000. The CPUE indices (1986–98) are not fitted in the base case because of concerns regarding their applicability to this species, but they do track the estimated biomass well.

The model shows the dominance of the 1991 cohort in the Campbell Island Rise stock; this cohort is estimated to be four times larger than any other cohort since 1979. As a result, the biomass increased from its lowest point in 1993 to its highest in 1996, but it has decreased since then. Nevertheless, the 2001 spawning biomass (SB_{2001}) is still estimated to be 1.7–7.3 times higher than SB_{1991}, which produced the huge cohort. Median SB_{2001} is 172,000 metric tons (mt) with 90% probability intervals of 76,000–428,000 mt. Future projections indicated that catch levels of 30,000 mt will result in only an 11% probability of the spawning biomass falling below SB_{1991} after 2 years. Thereafter, as the 1991 cohort diminishes further, catches will need to be reduced unless another strong cohort enters the fishery. The CAY catch is 29,600–34,700 mt depending on whether the median or the mean of the posterior distribution for spawning biomass is used in its calculation.

Sensitivities were performed which gave a similar picture to the base case, except that when the acoustic survey data were completely omitted, model biomass estimates were much more pessimistic. Historical CPUE data were remarkably consistent with the catch-at-age and acoustic data, indicating that CPUE analyses should perhaps be continued and included in future assessments. A retrospective analysis indicated that biomass was estimated at relatively high levels compared with current estimates, but this is confounded by the addition of successive acoustic surveys.

Future assessments need to resolve the issues of whether the CPUE data should be included in the assessment, the appropriate weighting for the catch-at-age data, and the estimation of annual varying selectivities to the fishery.

2. Introduction

2.1 Description of the Fishery

Southern blue whiting is confined to a sub-Antarctic distribution in New Zealand waters. The fish aggregate in August and September on four known spawning grounds: Bounty Platform, Pukaki Rise, Campbell Island Rise, and the Aukland Islands Shelf. Evidence from spawning timing, cohort analysis, and morphometrics suggest that these are all separate stocks (Hanchet 1999). The commercial fleet comprises mainly Japanese surimi and Russian head and gut vessels which also fish in the New Zealand west coast hoki (*Macruronus novaezelandiae*) fishery. Catch limits for southern blue whiting are often not reached, mainly owing to the relatively low value of this species and because of overlaps between the timing of the hoki and southern blue whiting fishing seasons, which cause fishing vessels to delay their arrival in this fishery. When the hoki fishing season extends into the southern blue whiting spawning period, the fleet often has insufficient time to locate the spawning aggregations of southern blue whiting before they disperse. The most important fishing ground for this species is the Campbell Island Rise, which has accounted for 55–85% of the total catch in recent years.

Only the Campbell Island Rise stock is assessed in this report.

2.2 MANAGEMENT CONTEXT FOR THIS STOCK ASSESSMENT

The stock assessment reported in this document was funded by the Hoki Management Company, Ltd (HMC), a company whose shareholders are the quota owners of the southern blue whiting fish stock, and was conducted jointly by the NZ Seafood Industry Council (SeaFIC) and the School of Aquatic and Fishery Sciences (SAFS) at the University of Washington (UW). A separate assessment of the Campbell Island Rise southern blue whiting stock was funded by the New Zealand Ministry of Fisheries (MFish) and was conducted by the National Institute of Water and Atmospheric Research (NIWA). Both stock assessments were presented to the Middle Depths Fishery Assessment Working Group (MDFAWG), which is sponsored and chaired by MFish and which serves as an independent peer review body. The report prepared by the MDFAWG, which integrates the results of the two available stock assessments, is the key management advice received by the Minister of Fisheries for formulating decisions regarding total allowable catches (TAC) for the coming fishing year.

2.3 DATA SOURCES

Biological parameters are available separately for males and females, but all southern blue whiting stock assessments to date have not distinguished between the sexes when modelling the stocks. In this assessment, parameters have been combined across sexes following this general practice. Natural mortality is estimated to be 0.2 based on the equation $M = \ln 100 / T_{max}$, where T_{max} is the age to which 1% of the population survives in an unexploited stock. With a maximum age of 22 years, M equals 0.21, which is rounded to 0.2 to reflect the imprecision of this estimate. Biological parameters are summarized in Table 1.

Observed weight-at-age data (S.M. Hanchet, unpubl. data) are used to calculate the biomass present in each year (Table 2). No weight-at-age data are available for 2001; the values used are the same as those used in the NIWA assessment, which are the average weight-at-age for each age from 1995 to 2000. Given the slow growth rates of the 1991 and later cohorts, this measure introduces an upward bias in estimates of the weights of the older fish. Since the 2001 weight-at-age data are used in estimates of the 2001 spawning biomass and also in the forward projections, this may result in slightly optimistic future projections.

Commercial catch-at-age data have been obtained from 1979 to the present, based on counting annual growth rings in otoliths (Hanchet 1996). The catch-at-age data are very consistent as strong cohorts can be tracked in the fishery for up to 20 years (Table 3). In the base case analysis, a plus group is used at 11+ years, as recommended by Hanchet (1996), mainly because there was less agreement between readers (and an indication of bias) for ages greater than 10. Estimated error in ageing is incorporated in the model using the information in Table 4.

Acoustic surveys were conducted on the Campbell Island Rise in 1993, 1994, 1995, 1998, and 2000. The first four surveys were originally decomposed into estimates of both adult and 2-year-old biomass (Table 5); but in 2001, the data for all the acoustic surveys were reanalyzed to provide biomass estimates for year classes 1, 2, 3 and 4+ (Table 6; S.M. Hanchet, NIWA, Nelson, New Zealand, unpubl. data).

The catch history used in the model is presented in Table 7. Only the catch history from 1978–79 is used in the model because catch data collected before this time were not available by area. No allowance is made for overruns due to discarding or accidental loss since there is no quantitative estimate of this factor. Although Campbell Island Rise catches are not known for the period 1971–1977, they are assumed to be 61.3% of the total catch in those years (Hanchet 1998). The fishing season (the catches used in the assessment) is assumed to include all catches from August to October in a particular year.

3. Methods: Base Case and Sensitivities

3.1 GENERAL MODEL DESCRIPTION

A generalized age-structured model (R. Hilborn et al., unpubl. report) was used to model the population dynamics of southern blue whiting. Model equations and the general specifications of the model are provided in Hilborn et al. (unpubl. report). The model is implemented to allow specification of prior probability distributions on estimated parameters so that Bayesian posterior distributions can be generated for parameters and performance indicators. Parameter estimates associated with the mode of the joint posterior distribution, called the Posterior Mode Estimate (MPD), were found by minimizing a total negative log-likelihood function using quasi-Newton minimization (AD Model Builder™, Otter Research, Ltd.).

The model was fitted to the commercial catch-at-age data (Table 3) and to the acoustic survey indices for 1, 2, 3 and 4+ age groups (Table 6). A scaling parameter (q) was estimated for each of these age groups using a lognormal

likelihood function. The catch-at-age data were fitted using a robust multinomial likelihood (Fournier et al. 1998), but with the variance term computed as a function of the observed proportions. The catch-at-age data are given a weighting proportional to the number of tows sampled in each year, with a median weighting of 100 for the base case.

Unlike many dynamic fishery population models, the starting model population was not assumed to be in equilibrium with recruitment. The initial conditions were set by a number of parameters, including the mean recruitment (R_0), the proportion of R_0 represented by the initial population, and the recruitment deviations for each age class in the model. The model also assumed that the population was fished prior to the beginning of the simulation by estimating an average exploitation for all ages (μ). Finally, a scalar was estimated which allowed the number of fish in the plus group (11+) in 1979 to be multiplied by a fixed value.

A fixed maturity ogive at age was used (Table 1), but selectivity to commercial fishing gear was modelled as a double half-Gaussian function of age, which is invariant over the simulation period (R. Hilborn et al., unpubl. report). This parameterization specifies the function using separate variance parameters for the left- and right-hand sides of the function and estimates the age at which the selectivity is at its maximum. The right-hand variance parameter was fixed at a sufficiently large value to ensure that the selectivity of the older fish did not decline from the maximum. No evidence in the data suggests that fishery selectivity had changed over the simulation period.

Bayesian estimation procedures were used to estimate uncertainty in model parameters, quantities, and projected quantities. Posterior distributions for parameters and quantities of interest were estimated using a Markov Chain Monte Carlo procedure (MCMC). The posteriors were based on 1,000 samples taken at regular intervals from 50 million MCMC simulations. For each sample, 5-year projections (from 2000–01 to 2005–06) were made under six levels of constant catch (ranging from 10,000 to 35,000 mt). In these projections, future recruitments (for 2001–06) were randomly generated from lognormally distributed recruitment deviations with standard deviation of 1.0; recruitments for the earlier years come from estimates of recruitment in those years.

3.2 Description of Changes Made in This Assessment

The main differences between this model and the one used in the previous assessments funded by the HMC and conducted by SeaFIC/UW are as follows:

- new acoustic survey estimates in the 2000 spawning season.
- all acoustic surveys decomposed into estimates for 1, 2, 3 and 4+ year olds; previously the biomass estimates were for immature and adult biomasses only.
- new series of catch-at-age data, and weight-at-age data for 2000.
- weighting of the catch-at-age data increased tenfold from 10 to 100.
- starting point in 1979 instead of 1971.

The revised starting point of 1979 was used because (a) there are no auxiliary data available prior to this year, (b) catch estimates are not available for individual areas before 1978 and must be assumed, and (c) it is easier to compare this model with the NIWA model if they each begin in the same simulation year.

The relative weight applied to the catch-at-age data was increased in this assessment because of the strong internal consistency in these data (Table 3). The MPD fits to the catch-at-age proportions can be used to obtain an empirical estimate of the effective sample sizes for each year (Eq. 1, A.E. Punt, SAFS, UW, Seattle, Washington, pers. comm.).

$$N_{effective}^{y} = \frac{\sum_{a=1}^{11+} p_{a,y}\left(1 - p_{a,y}\right)}{\sum_{a=1}^{11+} \left(p_{a,y} - p_{a,y}\right)^2} \qquad \text{(Eq. 1)}$$

where:

$N_{effective}^{y}$ = empirical estimate of sample size in year y,

$p_{a,y}$ = observed proportion of catch of age a in year y, and

$p_{a,y}$ = predicted proportion of catch of age a in year y.

The median sample size obtained using this measure is 68, somewhat lower than the 100 used in the base case, but it was only obtained after the MDFAWG agreed to use the value of 100. To compare the impact of the revised sample size value, we conducted initial sensitivities with model runs starting in 1971 and in 1979, but with a sample size of 10 on the catch-at-age data.

Comparison of model runs with equivalent runs from the NIWA model required conversion from start season biomass (B_{start}, this model) to mid-spawning season biomass (B_{mid}, NIWA model) biomass (Eq. 2).

$$B_{mid} = B_{start} \cdot e^{-0.95M} - 0.5 \cdot C \qquad \text{(Eq. 2)}$$

The pitfall in using B_{mid} comes when interpreting the forward projections because only half the catch in a particular year is removed, thus effectively understating the depletion in a given year. For this reason, only B_{start} values are reported in this paper.

3.3 MODEL RUN ASSUMPTIONS

3.3.1 Base Case

A list of the priors and starting parameter estimates used in the base case analysis is presented in Table 8. Natural mortality was fixed at 0.2 yr^{-1}.

3.3.2 Include CPUE Data

The CPUE data are available from 1986 to 1998 (Table 9). Concern has been expressed that CPUE data are not a reliable index of abundance for this stock. A decline in the biomass may not lead to a decline in the CPUE since the fishery can still target the aggregations. Conversely, an increase in biomass may not lead to an increase in the CPUE since the schools are highly mobile and the fishers may lose contact with the schools. For these reasons, the CPUE analysis was not conducted for 1999 and 2000. However, CPUE tracks abundance almost exactly, even when no attempt is made to fit the time series. In this sensitivity, the CPUE data are incorporated into the model fit, and the CPUE q estimated with a prior of ln q ~ Uniform (-15, 15).

3.3.3 Free Natural Mortality (M)

This sensitivity estimated M, using a uniform prior (0.0001, 0.6). In this fishery, the catch-at-age data in the earlier years are dominated by the plus group at 11+ years. This plus group comprises mainly fish from the 1965–67 cohort, which can be tracked through to 20 years in the catch-at-age data. Although we used a plus group of 11+ for this sensitivity, we also explored the effects of extending the plus group to 20+, using the data in Table 10. In the latter case, the weight-at-age of these older age groups is assumed to be the same as for the original 11+ age class. Ageing error is greater for these older age classes, so the ageing error matrix is updated (Table 11), based on the data in Hanchet (1996).

3.3.4 $M = 0.15$

The value of natural mortality was fixed at 0.15 yr^{-1} instead of 0.2 in the base case.

3.3.5 $M = 0.25$

The value of natural mortality was fixed at 0.25 yr^{-1} instead of 0.2 in the base case.

3.3.6 Absolute Survey Estimate

The survey estimates for all age classes were assumed to be absolute and not relative estimates by fixing the four ln q values at 0 (hence $q = 1$).

3.3.7 No Catch-at-Age Data, Survey Absolute

The catch-at-age data were not used in this sensitivity and the survey estimates were all assumed to be absolute estimates of biomass as described in Section 3.3.6.

3.3.8 No Acoustic Data

The acoustic data were omitted from the analysis, leaving only the catch-at-age data.

3.3.9 Recruitment Standard Deviation = 1.5

An independent Bayesian analysis using the NIWA model indicated that the most likely value for this parameter lies between 1 and 1.5 (V. Haist, SAFS, UW, Seattle, Washington, unpubl. analysis). As an alternative sensitivity, the recruitment SD was set to 1.5.

3.3.10 Catch-at-Age Data Weight = 10

In the base case, a "weighting" of 100 is assigned to the catch-at-age data. In previous years, a weighting of 10 had been used. For comparison, the analysis was re-run with a weight of 10 on the catch-at-age data.

3.3.11 Narrow Prior on R_0 (1; 205 million)

A concern was raised in the southern blue whiting working group that a uniform prior on R_0 over a very large range may cause an upward bias in the biomass estimates from the MCMC runs. The base case prior of (1; 10,000 million) resulted in a posterior distribution for R_0 with a 99% upper probability interval of 205 million. A sensitivity run was therefore conducted with a uniform prior of (1; 205 million) for R_0.

3.4 RETROSPECTIVE ANALYSIS

In order to investigate the possible bias in the estimation procedure, we conducted a retrospective analysis by successively removing the most recent year's data and repeating the analysis. This process was repeated to obtain assessments from 1979–95 to 1979–2000, ensuring that at least three acoustic surveys were included in each retrospective assessment.

3.5   Calculations of CAY

Simple calculations were made of the Current Annual Yield (CAY) for this fishery based on the simulation method proposed by Francis (1992b). This reference point is calculated as a constant fraction of the "pre-season" spawning biomass (Eq, 3–Eq. 5), which varies with natural mortality. The equations presented are only simple approximations since the CAY estimates will also depend on the selectivity ogive and recruitment variability, which were not used in the simulations.

$$CAY = 0.18 \cdot SB_{2001} \cdot e^{-0.15} \quad \text{for } M = 0.15 \text{ yr}^{-1} \quad \text{(Eq. 3)}$$
$$\text{(and Free } M \text{ case)}$$

$$CAY = 0.21 \cdot SB_{2001} \cdot e^{-0.20} \quad \text{for } M = 0.20 \text{ yr}^{-1} \quad \text{(Eq. 4)}$$

$$CAY = 0.24 \cdot SB_{2001} \cdot e^{-0.25} \quad \text{for } M = 0.25 \text{ yr}^{-1} \quad \text{(Eq. 5)}$$

4.   Results

4.1   Changes in the Model from the 1999–2000 Assessment

The previous SeaFIC/UW model (R. Hilborn, unpubl.; used for the 1999–2000 assessment) had used a catch-at-age weighting of 10 and had started in 1971 (Section 3.2). Increasing the catch-at-age weighting to 100 only increased the MPD estimate of the 2001 spawning biomass (SB_{2001}) by 2.5% (Fig. 1). However, starting the model in 1979 increased SB_{2001} by a further 28%. The overall impact of these two factors was to increase SB_{2001} by 31% over the previous methods.

4.2   Comparisons with the NIWA Model

The base case *mid-season* spawning biomass estimates from this model were very similar to those from the NIWA model under the assumption that RSD (recruitment standard deviation) was 1.0. Mid-season spawning biomass estimates were higher from the SeaFIC/UW model than the NIWA model for recent years when the RSD was assumed to be 1.5 (Fig. 2).

4.3   Estimates of the Maximum of the Posterior Density (MPD) for Key Parameters

The MPD results for the base case and the sensitivities are given in Table 12. When the posterior on R_0 is narrowed, the MPD estimates are identical to those in the base case, and hence these estimates are not discussed in this section.

The estimated selectivity-at-age for each of the sensi-

tivity runs is given in Table 13. When the catch-at-age data are removed (Case 3.3.7), there is no information left to estimate selectivity, and this case has anomalous selectivity estimates. For all other sensitivities explored, the shape of the estimated selectivity ogive was very similar, with almost no (<2%) 1- or 2-year-old fish selected, 52–70% of the 3-year-old fish selected, and full selectivity from age 4 onwards.

4.4   MPD Fits to the Data for the Base Case

In the base case, the model was fitted to the acoustic surveys and to the catch-at-age data. Model fits were good in both cases (Figs. 3 and 4).

4.5   MCMC Runs for the Base Case

Fifty million MCMC draws were taken and a sample of 1,000 taken for analysis (Fig. 5). Two convergence tests were examined: the first was a simple autocorrelation test between successive samples (should be <0.062), and the second split the samples into 10 sections and calculated the ratio of the means of the variances to the variance of the means of each section (should be <0.01; A.E. Punt, SAFS, UW, Seattle, Washington, pers. comm.). The autocorrelation test was 0.13, and the ratio test was 0.03. This indicates that only fair convergence was achieved despite the very long MCMC chain.

Recruitment in this fishery is highly variable and the available biomass is largely driven by the strength of the recruitments in the most recent year classes. Given this scenario, the concepts of equilibrium biomass levels or equilibrium yields are essentially meaningless. The MDFAWG therefore agreed that the spawning biomass level observed in 1991 was a threshold below which the current biomass should not be allowed to fall. This biomass level was selected for two reasons. First, the biomass in 1991 was estimated to be one of the lowest observed for this stock, but the stock still recovered to high levels. Second, the highest observed recruitment came from the 1991 year class, indicating that biomass levels as observed in 1991 were capable of producing high levels of recruitment. An alternative threshold level of 20% SB_{1979} proved to be almost identical in practice. The base case assessment (Section 3.3.1) estimated only a small probability (0.2%) that the current spawning biomass is below the 1991 level (Figs. 6 and 7).

Recruitment estimates indicated that the 1991 year class was by far the largest recruitment in the past two decades of this fishery (Fig. 8), although there is evidence of strong recruitment in the mid- to late-1960s from the catch-at-age data. The rapid recovery of the mature biomass from the

low level observed in 1991 is directly due to the recruitment of this large cohort into the vulnerable age classes (Fig. 9).

4.6 MCMC Runs with a Narrow Prior on R_0

There was little discernible difference (Fig. 10) in the posterior distribution of spawning biomass between the base case and the sensitivity run in which the prior on R_0 was considerably narrowed (Case 3.3.11). The means of the posterior distribution of SB_{2001} are within 1%, indicating that the wide prior used for R_0 in the base case had little impact on the results.

4.7 MCMC Runs for the Free M Case

The MPD estimate of natural mortality (M) was 0.159 yr^{-1} for the sensitivity run where this parameter was estimated (Case 3.3.3). An MCMC chain of 50 million was generated, but the convergence was much poorer than for the base case. The posterior distribution for M was shifted well to the left of the MPD estimate, with a mean of 0.310 yr^{-1} and 90% probability interval of (0.240, 0.370) (Fig. 11). These results contradict the MPD estimates and the fixed $M = 0.2$ used in the base case assessment.

4.8 Forward Projections under Fixed Catch Levels (Base Case)

The posterior distribution of biomass was projected forward under different levels of constant catch from 10,000 mt to 35,000 mt (Fig. 12). Under all catch levels, the spawning biomass declined as the numbers of the 1991 cohort decayed due to natural mortality. However, the posterior distribution of spawning biomass remains well above the 1991 spawning biomass level (the threshold level) for all catch levels over the next 2 years (Fig. 13, Table 14).

4.9 Retrospective Analysis

The retrospective analysis shows a consistent trend of declining biomass trajectories from 1995 to 2000 (Fig. 14). These six trajectories fall into three groups that correspond to the three most recent acoustic surveys (1995–1997 with the 1995 survey, 1998–1999 with the 1998 survey, and 2000 with the 2000 survey). These results suggest that the magnitude of the biomass levels is determined by the survey, while the direction of change (up or down) is determined by the catch-at-age data.

The large overestimates of the biomass levels in the middle 1990s possibly are due to the fixed selectivity used in the model to estimate the size of the age classes in the partially recruited age classes (ages 2 to 4). Given the large size of the 1991 cohort and its apparent slow growth (Sec-

tion 2.3), the model clearly overestimated the size of that cohort in those years.

4.10 CAY Estimates

Estimates of constant annual yield (CAY) are given in Table 15 for the MPD values in each sensitivity case, and in Table 16 for the posterior distribution of biomass from the base case. For the base case, the CAY is 29,600 mt for the median of the posterior and 34,700 mt for the mean of the posterior distribution (Table 16).

5. Discussion

MPD fits to the data were good, and the base case MCMC run achieved fair convergence. There was no apparent conflict between the commercial catch-at-age data and the survey data. Biomass indices based on commercial CPUE data (only available up to 1998) tracked the changes in biomass very closely, despite reservations about its usefulness given a population that is highly aggregated and quite mobile.

Southern blue whiting populations in the New Zealand southern ocean are affected by the great year-to-year variability in recruitment. There is evidence of very strong year classes in the late 1960s that dominated the population until the 1980s (Hanchet 1998), followed by below-average recruitment in the 1970s. The 1991 year class is the strongest observed in the last 2 decades and is estimated to be many times larger than any other year class (Fig. 8). Above-average recruitment also occurred in 1980, 1981, 1987, and 1996. The spawning biomass declined consistently from 1979 to 1993 under constant fishing and generally below average recruitment. The biomass recovered very quickly when the 1991 year class reached maturity, raising the spawning biomass to 3–5 times above the 1993 levels. Cohort growth rates appear to have slowed since the recruitment of the 1991 year class, with the implication of density-dependent growth. Model estimates of current spawning biomass are high relative to model estimates of biomass in the mid-1980s and early 1990s.

Model estimates of current biomass and other derived parameters were in close agreement with the equivalent estimates from the NIWA model. However, the changes made in the SeaFIC/UW 2001 stock assessment (increasing the weighting on the catch-at-age data and starting in 1979) resulted in more optimistic estimates of biomass compared with the previous SeaFIC/UW stock assessment. The decline estimated by this assessment also appears to be less than the predicted decline from previous assess-

ments because the most recent acoustic survey and the catch-at-age data are inconsistent with a steep drop in biomass.

The retrospective analysis shows the importance of the survey results in determining the biomass trajectory after the recruitment of the 1991 cohort. Biomass trajectories fall naturally into three groupings corresponding to the availability of results from the 1995, 1998, and 2000 acoustic surveys. There is some concern about the apparent overestimation of the biomass in earlier years of the retrospective analysis—this may be caused by a combination of slower growth rate after the recruitment of the 1991 cohort and fixed yearly selectivity. Estimating selectivity separately for each year may solve this problem.

The MPD estimates of current biomass for the different sensitivity cases are generally between 47% and 79% of B_{eq} (a proxy for B_0), and SB_{2001} is estimated to be 100,000–205,000 mt. The only sensitivity case outside this range is that in which the acoustic surveys are excluded (10%; 16,000 mt). It is, however, questionable whether B_{eq} has meaning for a species like southern blue whiting where recruitment is highly variable. Measures of B_{eq} are heavily dependent on average recruitment, which is sensitive to which period of years chosen. After some discussion, the working group agreed that a more meaningful reference point in this fishery would be the 1991 spawning biomass (SB_{1991}). In that year, not only was the spawning biomass at a low level, but that level of biomass gave rise to the largest pulse of recruitment in the past 2 decades. The working group therefore agreed to use SB_{1991} as a *threshold* biomass level (i.e., a level that the biomass should not be allowed to drop below).

Future projections indicate a low risk of the spawning biomass falling below SB_{1991} in the next 2 years. With a constant TAC of 20,000 mt for 2 years, there is a 4% probability of falling below this threshold; if the TAC is 35,000 mt, the probability increases to 14% after 2 years. However, as the strong 1991 year class disappears, spawning biomass will decline in the longer term. Without the addition of new strong year classes, there is a greater risk of falling below SB_{1991} after 2002–03.

6. Management Advice

- This stock is driven by wide fluctuations in recruitment. The appearance of a single large cohort would make future assessments considerably more optimistic. Conversely, several years of poor recruitment would result in a marked decline in biomass.
- The MPD estimates ("most likely" estimates) for

spawning biomass in 2001 range between 100,000 mt and 205,000 mt when the survey data are included.
- MPD estimates for Constant Annual Yield (CAY) range from 17,200–28,000 mt (Table 15).
- SB_{2001} is 1.7–7.3 times greater than SB_{1991} from the base case posterior distribution (90% probability intervals) (Fig. 7).
- The estimated CAY is 29,600 mt (median of the posterior distribution) or 34,700 mt (mean of the posterior distribution) (Table 16).
- On the basis of these analyses, the recommended catch for 2001–02 and 2002–03 is about 30,000 mt. Forward projections indicate a 12% probability that these catch levels will result in SB_{2003} falling below SB_{1991}.
- The spawning biomass will decrease regardless of the catch level in 2001–02 because the massive 1991 cohort will dwindle through natural mortality. Under the CAY strategy, catches of southern blue whiting will therefore need to be much lower than 30,000 mt in the future to reduce the probability of falling below SB_{1991} unless there is evidence of another strong pulse of recruitment.

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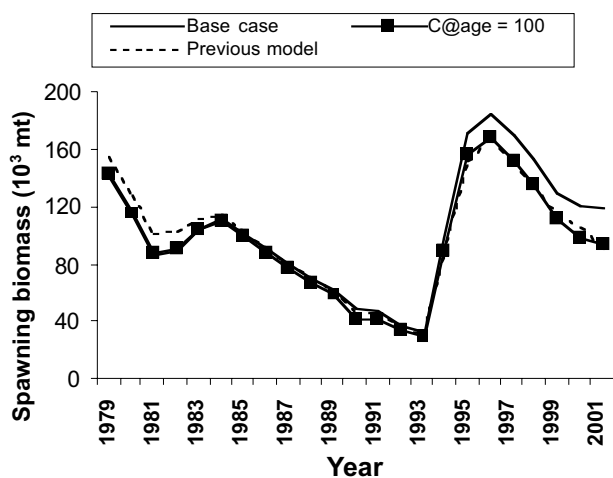
FIGURE 1. Effects of changes in the specifications from those used in the previous (1999) model, i.e. a catch-at-age weighting of 10, and model start in 1971. The impact of increasing the weighting to 100, and then additionally starting the model in 1979 (the base case used in this assessment), is shown.
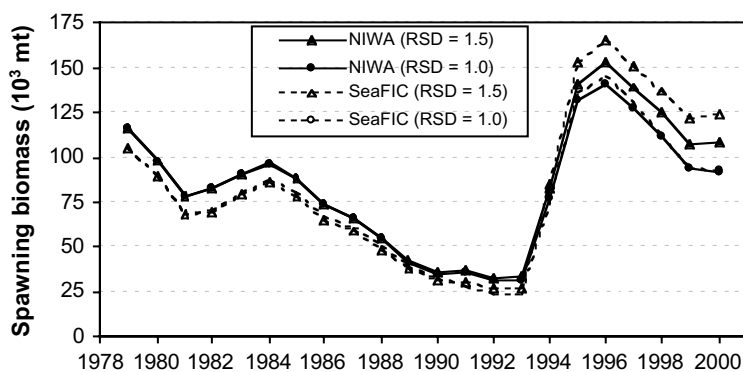
FIGURE 2. Comparison of estimates of spawning biomass (converted to mid-season) between the NIWA and SeaFIC/UW models. The RSD (recruitment standard deviation) is constrained in the NIWA model to enable comparisons to be made between the two models (S. Hanchet, S. Hanchet, NIWA, Nelson, New Zealand, and V. Haist, UW Aquatic & Fishery Sciences, Seattle, Washington, USA, unpubl. data). The SeaFIC runs correspond to Cases 3.3.1 (RSD = 1.0) and 3.3.9 (RSD = 1.5).
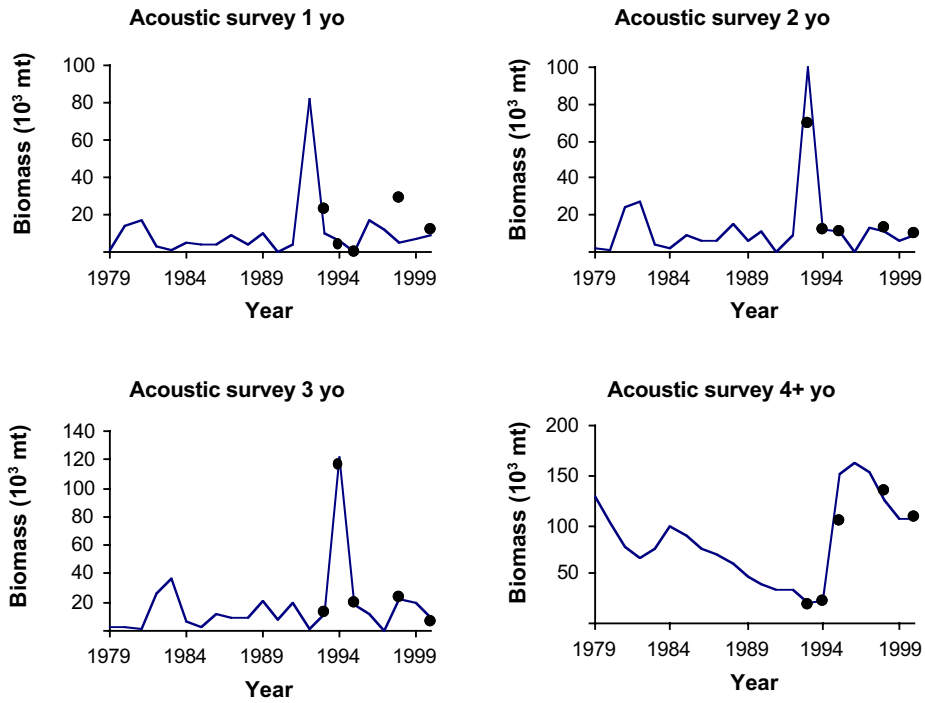
FIGURE 3.   Predicted values (lines) and actual data (points) for the acoustic surveys for the base case. The predicted values are start-season spawning biomass values.
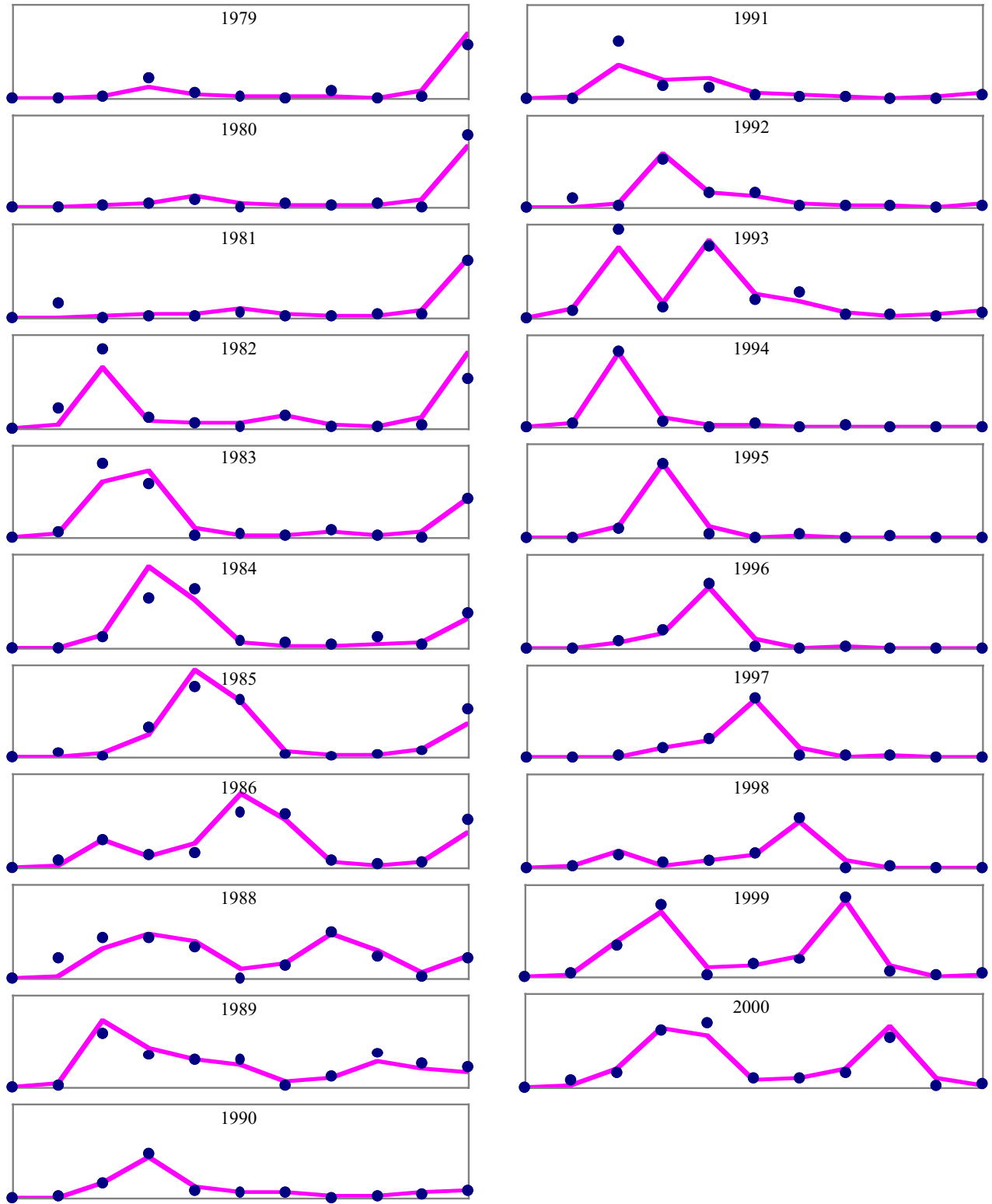
FIGURE 4. Predicted values (lines) and actual data (points) for the MPD fits to the catch-at-age data for the base case. The plus group is 11+ years. No data were collected in 1987.
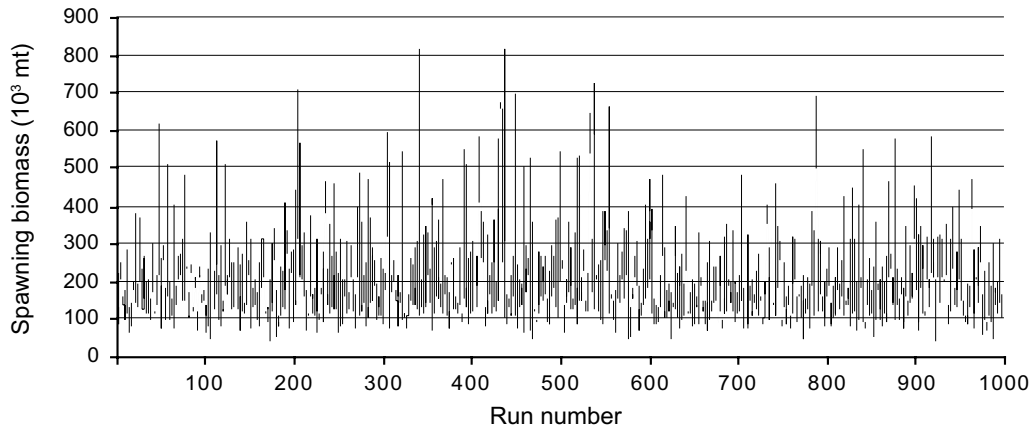
FIGURE 5. Trace of SB_{2001} from the MCMC runs for the base case with 1,000 samples from 50 million draws.
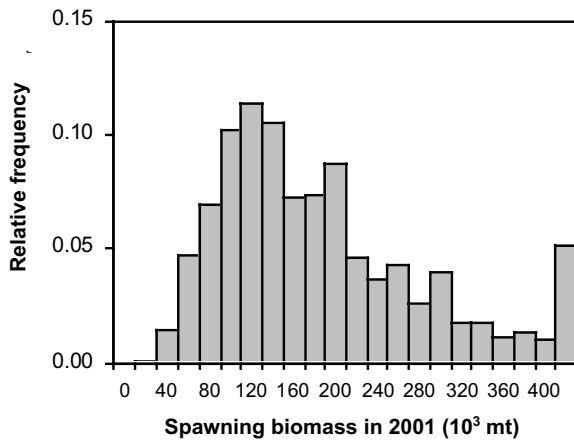
FIGURE 6. Posterior distribution of the spawning biomass at the start of 2001.
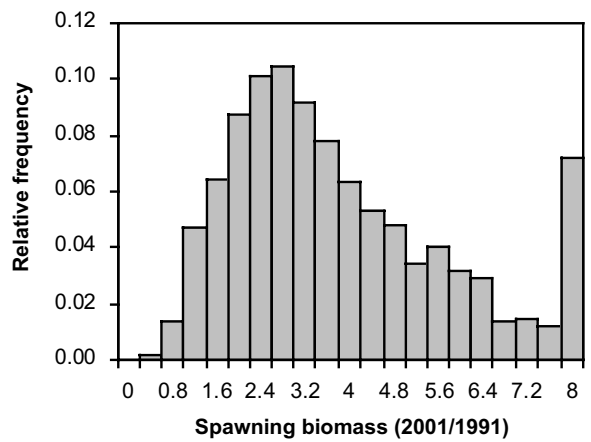
FIGURE 7. Posterior for the ratio of SB_{2001} to SB_{1991}.
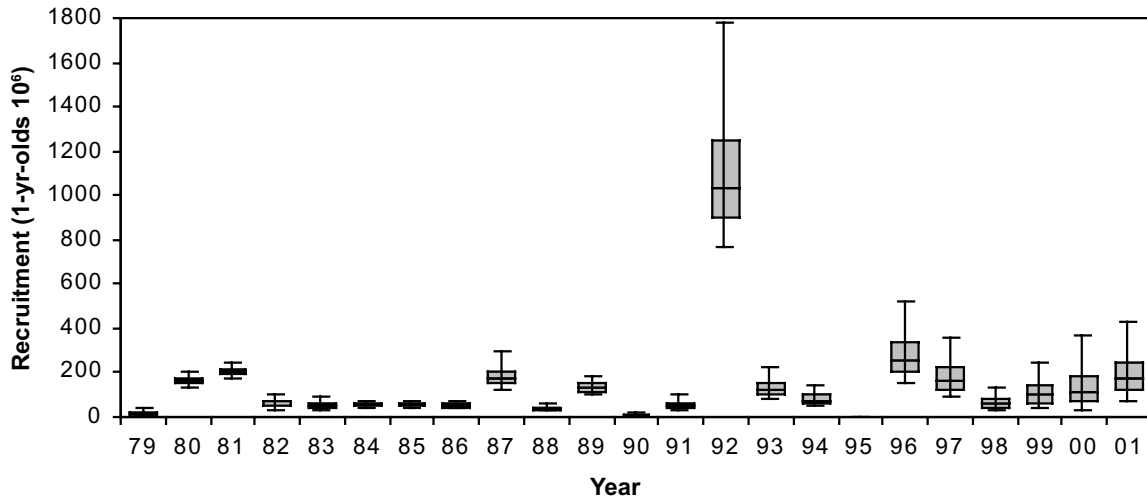
FIGURE 8. Estimated recruitment of one-year-old fish in each year, showing the dominance of the 1991 year class in the 1992 recruitment. The 5%, 25%, 50%, 75% and 95% probability intervals are indicated. The 1995 year class is estimated to be so small that even the upper bounds are not discernable from zero in this graph.
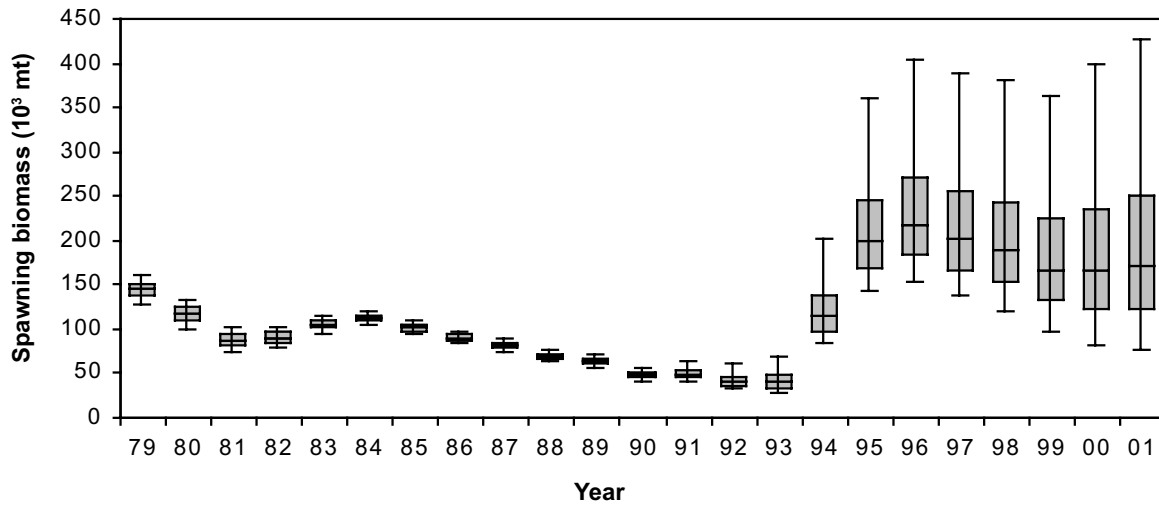
FIGURE 9. Estimated spawning biomass in each year, showing the 5%, 25%, 50%, 75% and 95% probability intervals.
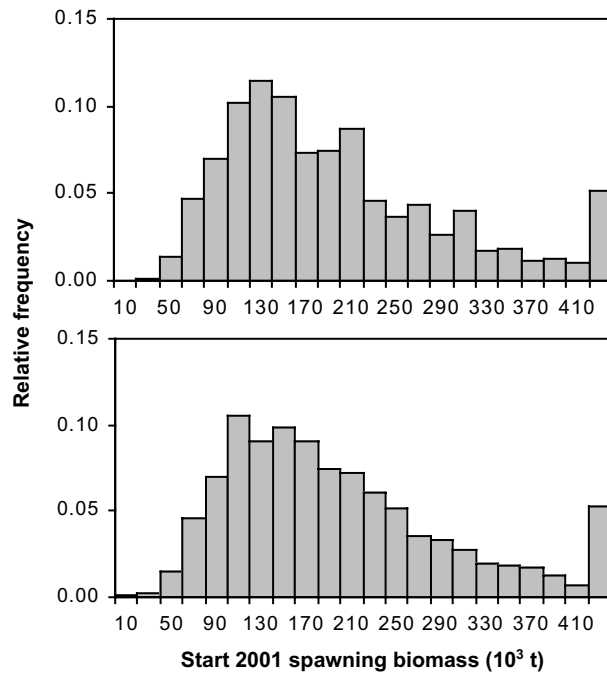
FIGURE 10. Comparison of the posteriors for the spawning biomass in 2001 under the base case (3.3.1) compared with the case where the prior on R_0 was narrowed considerably (3.3.11). Spawning biomass is at the start of the year.
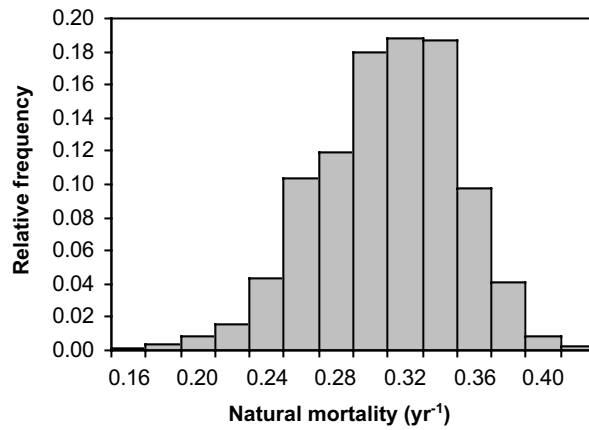
FIGURE 11. Posterior for natural mortality under the Free *M* case (3.3.3).
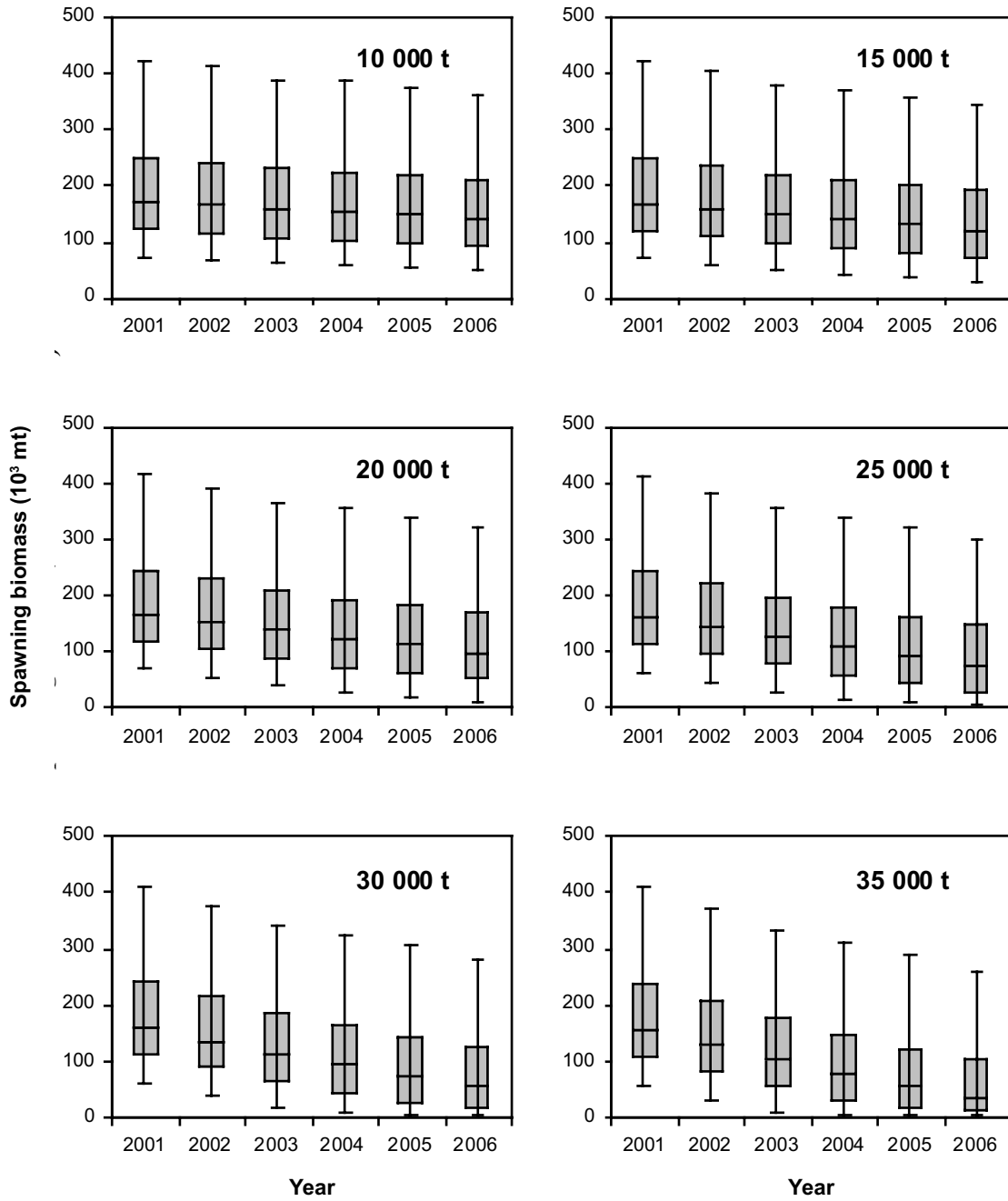
FIGURE 12. Forward projections of spawning stock biomass under different constant catch levels from 10,000 mt to 35,000 mt per year over the next five years. The 5%, 25%, 50%, 75% and 95% probability intervals are indicated in each year.
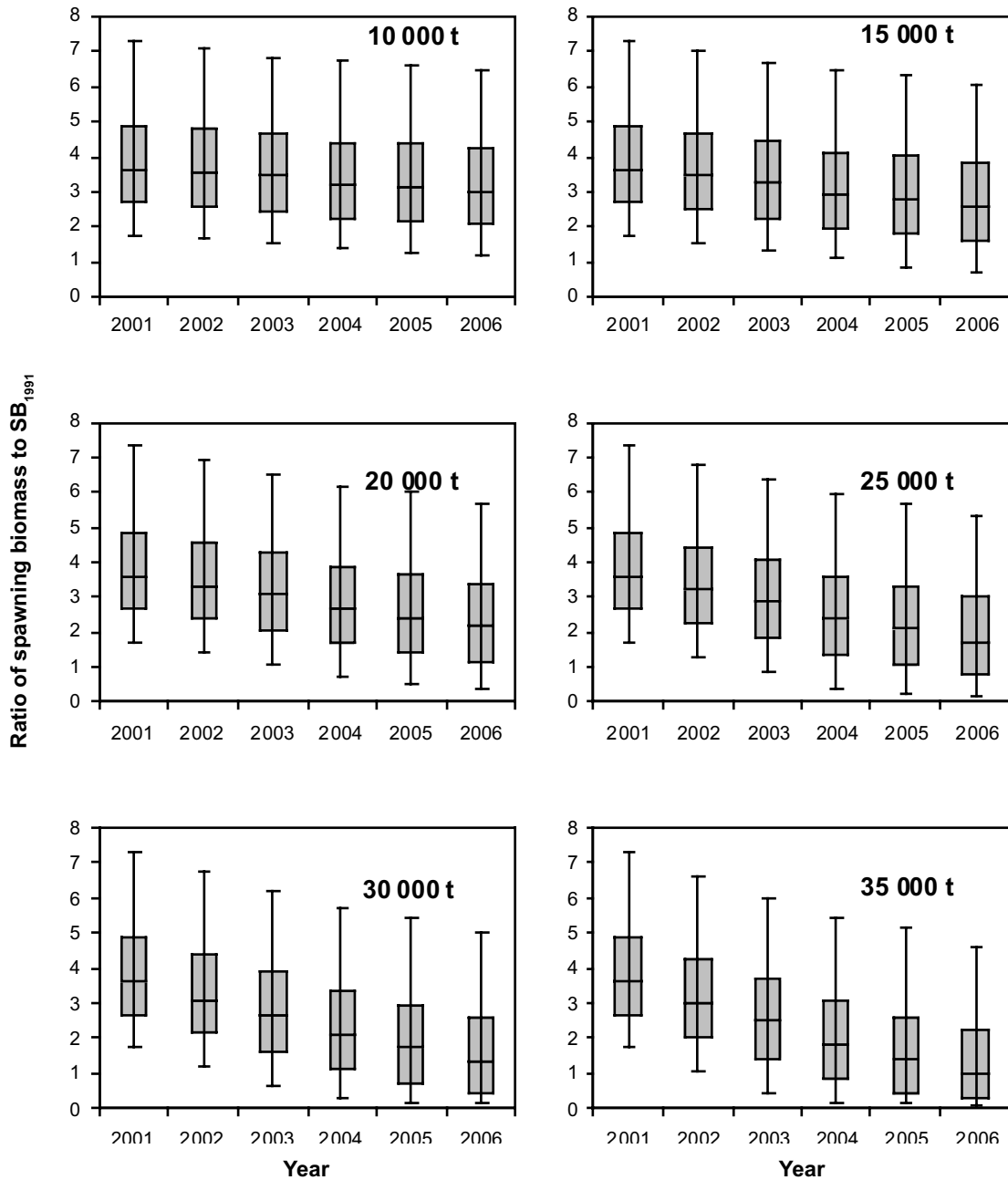
FIGURE 13. Ratio of spawning biomass relative to that in 1991, under fixed catch levels of 10,000 mt to 35,000 mt per year over the next five years. The 5%, 25%, 50%, 75% and 95% probability intervals are indicated in each year. Spawning biomass levels are for the start of the year.
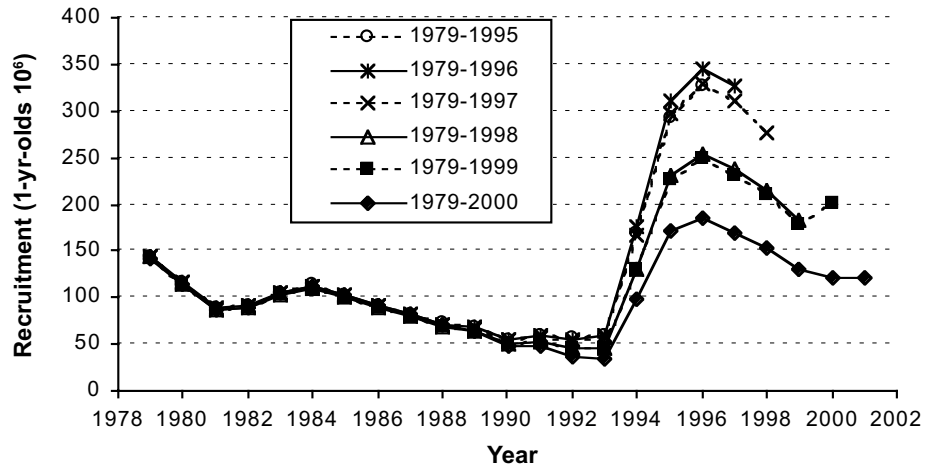
FIGURE 14. Retrospective analysis showing the changes in the trajectory of spawning biomass if data from the most recent 5 years are iteratively removed, i.e. the analysis is performed using only data from 1979-1995, then 1979-1996 etc. Spawning biomass is at the beginning of the year.

TABLE 1. Summary of biological parameters used for modeling southern blue whiting on the Campbell Island Rise (S. Hanchet, NIWA, Nelson, New Zealand, unpubl. rep.). The parameters in the "Combined" column were used in the model as it was not sex-specific.

Parameter	Male	Female	Combined	Source
Natural mortality M			**0.2**	**Hanchet (1992)**
Proportion mature age 2			0.05	Hanchet (unpubl. rep.)
Proportion mature age 3			0.55	Hanchet (unpubl. rep.)
Proportion mature age 4			0.95	Hanchet (unpubl. rep.)
Proportion mature age 5+			1.00	Hanchet (unpubl. rep.)
Von Bertalanffy L_∞^1	47.6	51.5	49.3	Hanchet (1991)
Von Bertalanffy k^1	0.35	0.32	0.35	Hanchet (1991)
Von Bertalanffy t_0^1	-0.93	-1.03	-0.8	Hanchet (1991)
Length-weight a^1	0.00515	0.00407	0.00439	Hanchet (1991)
Length-weight b^1	3.092	3.152	3.133	Hanchet (1991)
Recruitment variability (=standard deviation)	1.0	1.0	1.0	
Steepness[2]	0.95	0.95	0.95	

[1] These values are not used in the model since observed weight-at-age is available (see below); they are included for completeness.

[2] Mean recruitment (as a fraction of unexploited recruitment) at 20% of pristine spawning biomass (Francis 1992a), for the Beverton-Holt stock-recruit relationship.

TABLE 2. Weight-at-age (kg) for southern blue whiting in the Campbell Island Rise (S. Hanchet, NIWA, Nelson, New Zealand, unpubl. rep.). The 2001 data are used to estimate SB_{2001} and in the future projections, see text for details on how the 2001 catch-at-age data are estimated.

Year	1	2	3	4	5	6	7	8	9	10	11+
1979	0.1	0.244	0.316	0.446	0.528	0.613	0.593	0.655	0.654	0.616	0.636
1980	0.1	0.193	0.325	0.457	0.503	0.544	0.606	0.69	0.622	0.812	0.773
1981	0.1	0.208	0.276	0.537	0.512	0.623	0.625	0.721	0.696	0.683	0.744
1982	0.1	0.193	0.285	0.446	0.599	0.634	0.652	0.714	0.740	0.771	0.832
1983	0.1	0.207	0.314	0.391	0.543	0.576	0.660	0.680	0.755	0.785	0.799
1984	0.1	0.193	0.386	0.454	0.531	0.617	0.619	0.694	0.710	0.747	0.756
1985	0.1	0.211	0.399	0.480	0.547	0.622	0.679	0.669	0.726	0.759	0.796
1986	0.1	0.193	0.356	0.522	0.543	0.599	0.656	0.712	0.786	0.802	0.810
1987	0.1	0.212	0.343	0.465	0.568	0.651	0.715	0.763	0.799	0.826	0.845
1988	0.1	0.196	0.348	0.488	0.543	0.517	0.702	0.720	0.755	0.954	0.950
1989	0.1	0.186	0.342	0.475	0.560	0.673	0.773	0.759	0.783	0.813	0.862
1990	0.1	0.144	0.339	0.472	0.580	0.646	0.709	0.788	0.812	0.825	0.858
1991	0.1	0.134	0.302	0.490	0.596	0.727	0.784	0.787	0.909	0.899	0.966
1992	0.1	0.254	0.351	0.469	0.632	0.717	0.777	0.791	0.831	0.960	0.961
1993	0.1	0.150	0.378	0.506	0.582	0.745	0.790	0.863	0.905	0.867	1.001
1994	0.1	0.146	0.223	0.515	0.610	0.667	0.804	0.854	0.934	0.939	1.150
1995	0.1	0.228	0.278	0.324	0.562	0.620	0.704	0.876	0.822	0.963	0.993
1996	0.1	0.219	0.279	0.350	0.407	0.743	0.779	0.811	0.883	0.904	0.977
1997	0.1	0.093	0.334	0.392	0.403	0.488	0.713	0.804	0.831	0.881	0.939
1998	0.1	0.107	0.195	0.382	0.491	0.487	0.551	0.828	0.869	0.923	0.938
1999	0.1	0.154	0.244	0.301	0.424	0.487	0.496	0.552	0.733	0.763	0.858
2000	0.1	0.159	0.300	0.344	0.418	0.514	0.610	0.625	0.682	0.854	0.955
2001	0.1	0.160	0.272	0.349	0.451	0.557	0.642	0.749	0.803	0.881	0.943

TABLE 3. Proportion of fish in each age class in the commercial fishery, and the number of tows sampled in each year (S. Hanchet, NIWA, Nelson, New Zealand, unpubl. rep.).

Year	Tows (n)	Age (yrs)										
		1	2	3	4	5	6	7	8	9	10	11+
1979	20	0	0.009	0.022	0.214	0.068	0.016	0.009	0.073	0.009	0.021	0.559
1980	10	0	0.002	0.013	0.030	0.070	0.009	0.031	0.023	0.037	0.005	0.781
1981	33	0	0.156	0.009	0.021	0.018	0.059	0.026	0.012	0.045	0.042	0.611
1982	16	0	0.107	0.418	0.063	0.026	0.014	0.068	0.011	0.009	0.022	0.262
1983	17	0	0.034	0.388	0.281	0.012	0.016	0.012	0.042	0.010	0.000	0.205
1984	13	0	0.002	0.057	0.268	0.315	0.040	0.028	0.024	0.058	0.019	0.188
1985	17	0	0.024	0.011	0.131	0.304	0.247	0.015	0.008	0.015	0.032	0.213
1986	28	0	0.031	0.115	0.054	0.064	0.234	0.228	0.030	0.017	0.025	0.203
1988	206	0	0.085	0.169	0.169	0.133	0.004	0.052	0.196	0.097	0.006	0.089
1989	133	0	0.004	0.236	0.139	0.116	0.115	0.009	0.051	0.147	0.099	0.083
1990	94	0	0.027	0.149	0.476	0.084	0.062	0.057	0.009	0.017	0.044	0.075
1991	52	0	0.003	0.613	0.140	0.127	0.034	0.023	0.011	0.005	0.009	0.035
1992	121	0	0.097	0.019	0.505	0.152	0.150	0.017	0.018	0.013	0.002	0.025
1993	55	0	0.033	0.378	0.043	0.304	0.076	0.107	0.015	0.013	0.007	0.023
1994	80	0	0.034	0.833	0.066	0.004	0.037	0.007	0.016	0.001	0.001	0.003
1995	76	0	0.004	0.103	0.791	0.042	0.002	0.031	0.005	0.016	0.001	0.004
1996	96	0	0.000	0.069	0.194	0.695	0.013	0.003	0.015	0.003	0.004	0.004
1997	185	0	0.003	0.029	0.097	0.190	0.622	0.017	0.014	0.013	0.005	0.009
1998	255	0	0.017	0.144	0.055	0.072	0.153	0.524	0.010	0.012	0.008	0.006
1999	175	0	0.015	0.140	0.312	0.011	0.055	0.075	0.346	0.021	0.006	0.018
2000	168	0	0.034	0.064	0.244	0.277	0.037	0.042	0.065	0.214	0.008	0.015

TABLE 4. Estimated ageing error, derived from age reader comparisons in Hanchet (1996).

Estimated age (yrs)	Real age (yrs)										
	1	2	3	4	5	6	7	8	9	10	11+
1	0.95	0.05	0	0	0	0	0	0	0	0	0
2	0.05	0.90	0.05	0	0	0	0	0	0	0	0
3	0	0.05	0.90	0.05	0	0	0	0	0	0	0
4	0	0	0.05	0.90	0.1	0	0	0	0	0	0
5	0	0	0	0.05	0.8	0.1	0	0	0	0	0
6	0	0	0	0	0.1	0.8	0.1	0	0	0	0
7	0	0	0	0	0	0.1	0.8	0.1	0	0	0
8	0	0	0	0	0	0	0.1	0.8	0.1	0	0
9	0	0	0	0	0	0	0	0.1	0.8	0.1	0
10	0	0	0	0	0	0	0	0	0.1	0.8	0.1
11+	0	0	0	0	0	0	0	0	0	0.1	0.9

TABLE 5. Survey indices for the 1993, 1994, 1995 and 1998 acoustic surveys on southern blue whiting on the Campbell Island Rise. These were used in previous assessments, and are decomposed into two-year-old and mature age groups. The cvs are assumed values.

	2 year old		Spawning adults	
Year	Biomass (t)	cv	Biomass (t)	cv
1993	89,600	0.5	18,500	0.35
1994	22,400	0.5	161,400	0.35
1995	19,800	0.5	121,100	0.35
1998	13,000	0.5	171,500	0.25

TABLE 6. Survey indices used in this assessment. All the acoustic surveys have been re-analysed to provide estimates for 1, 2, 3 and 4+ year-olds, and the additional 2000 survey has been added. The cvs are assumed values.

	1 year old		2 year old		3 year old		4+ years	
Year	Biomass (t)	cv	Biomass (t)	cv	Biomass (t)	cv	Biomass (t)	cv
1993	1,817	0.7	71,902	0.5	14,781	0.35	24,033	0.35
1994	329	0.7	12,259	0.5	139,552	0.35	28,841	0.35
1995	0[1]	0.7	11,176	0.5	23,228	0.35	130,535	0.35
1998	2,283	0.7	13,142	0.5	28,022	0.25[2]	167,668	0.25[2]
2000	961	0.7	10,460	0.5	8,421	0.35	135,612	0.35

[1]Model fit problems led to a value of 0.1 being used in this assessment.
[2]A lower cv is assigned to the 1998 survey estimates for 3 and 4+ year old fish, because more acoustic snapshots were obtained in that survey than in the other years.

TABLE 7. Estimated catches of southern blue whiting in the Campbell Island Rise and total catch in the New Zealand fishery (Annala et al. 2001). The model in this assessment uses catch data from 1978-79 onwards only.

Fishing year	Model year	Total for New Zealand		Campbell Island Rise (plenary)		Campbell (assessment)
		Catch	Catch limit	Catch	Catch limit	Catch
1971	1971	10,400	–	?	–	6,373
1972	1972	25,800	–	?	–	15,810
1973	1973	48,500	–	?	–	29,720
1974	1974	42,200	–	?	–	25,859
1975	1975	2,378	–	?	–	1,457
1976	1976	17,089	–	?	–	10,466
1977	1977	26,435	–	?	–	16,199
1978*	1978	6,497	–	6,403	–	6,403
1978–79+	1979	28,136	–	25,305	–	25,305
1979–80+	1980	18,633	–	12,828	–	12,828
1980–81+	1981	8,466	–	5,989	–	5,989
1981–82+	1982	17,595	–	7,915	–	7,915
1982–83+	1983	24,239	–	12,803	–	12,803
1983–84+	1984	13,374	–	10,777	–	10,777
1984–85+	1985	9,335	–	7,490	–	7,490
1985–86+	1986	15,819	–	15,252	–	15,252
1986–87+	1987	13,710	–	12,804	–	12,804
1987–88+	1988	17,601	–	17,422	–	17,422
1988–89+	1989	27,839	–	26,611	–	26,611
1989–90+	1990	22,365	–	16,542	–	16,542
1990–91+	1991	36,870	–	21,314	–	21,314
1991–92+	1992	76,255	–	14,208	–	14,208
1992–93+	1993	27,708	32,000	9,316	11,000	9,316
1993–94+	1994	18,560	32,000	11,668	11,000	11,668
1994–95+	1995	17,477	32,000	9,492	11,000	10,436
1995–96+	1996	22,279	32,000	14,959	21,000	16,504
1996–97+	1997	18,374	58,000	15,685	30,100	18,923
1997–98+	1998	31,165	58,000	24,273	35,460	27,164
1998–00†	1999	40,926	58,000	30,386	35,460	27,205
2000–01‡	2000	24,743	35,140	18,049	20,000	18,049

*1 April-30 September

+1 October-30 September

†1 October 1998-31 March 2000

‡1 April 2000-31 March 2001

TABLE 8. Priors used in the SeaFIC model for Campbell Island Rise southern blue whiting.

Parameter	Lower bound	Upper bound	Prior type	Mean	SD	Initial value
R_0 (000)	1	10,000,000	Uniform	NA	NA	50,000
Initial R (fraction of R_0)	0	10	Uniform	NA	NA	1
Log recruitment deviations	-15	15	Normal	0	1	0
Log deviations initial age structure	-15	15	Normal	0	1	0
Exploitation rate on initial age structure	0	0.1	Uniform	NA	NA	0.1
Plus scale for initial age structure	0	100	Uniform	NA	NA	50
Log q survey 1 year old	-5	5	Uniform	NA	NA	0
Log q survey 2 year old	-5	5	Uniform	NA	NA	0
Log q survey 3 year old	-5	5	Uniform	NA	NA	0
Log q survey 4+ year old	-5	5	Uniform	NA	NA	0
Selectivity parameters:						
S fullest for length (age in years)	2	11	Uniform	NA	NA	3.45
Log variance of left side of selectivity curve for length	-15	15	Uniform	NA	NA	-0.4

TABLE 9. Standardized CPUE data available for the Campbell Island Rise southern blue whiting stock (from Hanchet 2000). The cv in each year is assumed.

Year	CPUE index	cv
1986	1.00	0.5
1987	0.72	0.5
1988	0.59	0.5
1989	0.60	0.5
1990	0.52	0.5
1991	0.52	0.5
1992	0.27	0.5
1993	0.69	0.5
1994	0.74	0.5
1995	1.30	0.5
1996	1.54	0.5
1997	1.03	0.5
1998	0.99	0.5

TABLE 10. Proportion of fish in each age class above 10 years old used in exploratory analyses of the "Free *M*" sensitivity, showing the breakdown of proportions at each age in the 11+ group in the base case (S. Hanchet, NIWA, Nelson, New Zealand, unpubl. rep.).

	Base	Free *M* sensitivity case									
Year	11+	11	12	13	14	15	16	17	18	19	20+
1979	0.559	0.044	0.080	0.080	0.129	0.166	0.045	0.012	0.000	0.000	0.000
1980	0.781	0.035	0.070	0.072	0.125	0.213	0.124	0.104	0.038	0.000	0.000
1981	0.611	0.012	0.037	0.062	0.066	0.103	0.112	0.118	0.074	0.014	0.009
1982	0.262	0.028	0.012	0.007	0.015	0.023	0.011	0.062	0.068	0.025	0.010
1983	0.205	0.022	0.016	0.000	0.005	0.017	0.016	0.021	0.066	0.026	0.017
1984	0.188	0.005	0.008	0.028	0.011	0.013	0.010	0.010	0.014	0.035	0.054
1985	0.213	0.016	0.009	0.041	0.029	0.023	0.011	0.022	0.002	0.016	0.045
1986	0.203	0.026	0.008	0.013	0.014	0.019	0.011	0.012	0.008	0.027	0.065
1988	0.089	0.014	0.006	0.014	0.006	0.012	0.014	0.008	0.002	0.001	0.014
1989	0.083	0.030	0.005	0.013	0.007	0.008	0.001	0.008	0.007	0.000	0.003
1990	0.075	0.038	0.008	0.002	0.008	0.007	0.001	0.000	0.005	0.002	0.004
1991	0.035	0.014	0.009	0.004	0.002	0.001	0.002	0.001	0.001	0.001	0.000
1992	0.025	0.008	0.005	0.006	0.004	0.000	0.000	0.002	0.001	0.000	0.000
1993	0.023	0.003	0.002	0.010	0.003	0.001	0.000	0.000	0.001	0.000	0.002
1994	0.003	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.004	0.001	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
1996	0.004	0.001	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000
1997	0.009	0.006	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.006	0.004	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.018	0.004	0.007	0.004	0.000	0.002	0.000	0.000	0.001	0.000	0.000
2000	0.015	0.004	0.006	0.002	0.002	0.001	0.000	0.000	0.000	0.000	0.000

TABLE 11. Spread of age classes caused by uncertainty in ageing, when the plus group at age 11+ years is split into year classes up to 20+. Estimates are derived from age reader comparisons in Hanchet (1996).

Estimated	Real age (yrs)									
age (yrs)	11	12	13	14	15	16	17	18	19	20+
10	0.1	0.1	0	0	0	0	0	0	0	0
11	0.8	0.2	0.1	0	0	0	0	0	0	0
12	0.1	0.4	0.2	0.1	0	0	0	0	0	0
13	0	0.2	0.4	0.2	0.1	0	0	0	0	0
14	0	0.1	0.2	0.4	0.2	0.1	0	0	0	0
15	0	0	0.1	0.2	0.4	0.2	0.1	0	0	0
16	0	0	0	0.1	0.2	0.4	0.2	0.1	0	0
17	0	0	0	0	0.1	0.2	0.4	0.2	0.1	0
18	0	0	0	0	0	0.1	0.2	0.4	0.2	0.1
19	0	0	0	0	0	0	0.1	0.2	0.4	0.2
20+	0	0	0	0	0	0	0	0.1	0.3	0.7

TABLE 12. Results of the model runs from the base case and the sensitivity runs, giving the maximum of the posterior density (MPD) and the likelihood components for the mode fits. Spawning biomass is for start year spawning biomass as detailed in Section 3.3. The MPD results of Case 3.3.11 are identical to the base case and are omitted from this table. R_{eq} is the mean estimated recruitment of 1-year-olds from 1979 to 1997 and B_{eq} is R_{eq} * spawning-biomass-per-recruit—these are proxies for R_0 and B_0.

	Case 3.3 Base Case	Case 3.3.2 Include CPUE	Case 3.3.3 Free M	Case 3.3.4 M = 0.15	Case 3.3.5 M = 0.25	Case 3.3.6 Absolute survey	Case 3.3.7 No catch at age	Case 3.3.8 No Acoustic	Case 3.3.9 Rec std 1.5	Case 3.3.10 Catch age wt = 10
Acoustic survey used	relative weight 100	Relative weight 100	Relative weight 100	relative weight 100	Relative weight 100	absolute weight 100	absolute weight 100	not used weight 100	relative weight 100	relative weight 100
Catch at age	weight 100	weight 100	weight 100	weight 100	weight 100	weight 100	not used	weight 100	weight 100	weight 10
CPUE used	no	yes	No	no	No	no	no	no	no	no
Natural mortality, M (yr⁻¹)	0.2	0.2	0.159	0.15	0.25	0.2	0.2	0.2	0.2	0.2
Recruitment SD	1	1	1	1	1	1	1	1	1.5	1
Likelihoods										
Commercial catch at age	-246.4	-246.6	-243.5	-245.5	-243.9	-245.6	–	-247.6	-247.3	-349.0
Acoustic age 1	12.0	12.2	12.3	12.3	12.1	23.6	19.1	–	5.6	11.6
Acoustic age 2	0.3	0.4	0.3	0.3	0.4	0.4	2.1	–	0.3	0.2
Acoustic age 3	0.4	0.3	0.6	0.5	0.4	0.8	0.7	–	0.5	1.1
Acoustic age 4+	0.6	0.7	0.4	0.4	0.6	1.0	0.8	–	0.5	0.5
CPUE	–	1.5	–	–	–	–	–	–	–	–
Penalties	29.5	29.4	28.0	30.0	28.8	41.7	33.2	13.5	19.1	25.3
Total likelihood	-203.6	-202.0	-202.0	-202.1	-201.6	-178.0	55.8	-234.1	-221.3	-310.4
Parameters										
Acoustic q age 1	0.08	0.09	0.10	0.10	0.05	1	1	–	0.10	0.07
Acoustic q age 2	1.01	1.11	1.21	1.29	0.62	1	1	–	0.88	0.92
Acoustic q age 3	1.20	1.31	1.27	1.36	0.74	1	1	–	0.98	1.11
Acoustic q age 4+	1.21	1.34	1.30	1.38	0.78	1	1	–	1.02	1.16
CPUE q	–	9.5E-06	–	–	–	–	–	–	–	–
Derived parameters										
R_{eq} (millions)	117.1	110.8	93.1	86.6	195.5	119.3	101.5	86.0	130.2	118.7
Start year B_{eq} (t)	219,000	207,000	244,000	245,000	258,000	223,000	190,000	161,000	244,000	222,000
Start year SB_{2001} (t)	121,000	100,000	124,000	114,000	205,000	123,000	132,000	16,000	163,000	130,000
Start year SB_{2001}/B_{eq}	55%	48%	51%	47%	79%	55%	69%	10%	67%	59%

TABLE 13. Estimated commercial selectivity-at-age for the southern blue whiting fishery on the Campbell Island Rise under the base case and the different sensitivities.

	Case 3.3.1 Base Case	Case 3.3.2 Include CPUE	Case 3.3.3 Free M	Case 3.3.4 $M = 0.15$	Case 3.3.5 $M = 0.25$	Case 3.3.6 Absolute survey	Case 3.3.7 No catch at age	Case 3.3.8 No acoustic	Case 3.3.9 Rec std 1.5	Case 3.3.10 Catch age wt = 10
Selectivity age 1	0	0	0	0	0	0	0	0	0	0
Selectivity age 2	0.002	0.002	0.002	0.002	0.002	0.002	0	0.029	0.002	0.004
Selectivity age 3	0.522	0.523	0.699	0.683	0.668	0.673	0	0.528	0.676	0.564
Selectivity age 4	1	1	1	1	1	1	0	1	1	1
Selectivity age 5+	1	1	1	1	1	1	1	1	1	1

TABLE 14. Estimated probability that the spawning biomass will fall below that in 1991 under different fixed catches projected forward for 5 years, for the base case. Spawning biomass levels are for the start of the year, the current spawning biomass is given in the first column.

Catch Levels	Year					
	$P(SB_{2001} < SB_{1991})$	$P(SB_{2002} < SB_{1991})$	$P(SB_{2003} < SB_{1991})$	$P(SB_{2004} < SB_{1991})$	$P(SB_{2005} < SB_{1991})$	$P(SB_{2006} < SB_{1991})$
10,000 t	0.2%	0.4%	1.1%	1.9%	2.4%	2.9%
15,000 t	0.2%	0.9%	2.3%	4.4%	6.3%	8.7%
20,000 t	0.2%	1.5%	3.7%	8.1%	14.1%	19.3%
25,000 t	0.2%	2.2%	6.9%	14.8%	23.5%	30.6%
30,000 t	0.2%	3.2%	10.6%	22.9%	33.4%	41.7%
35,000 t	0.2%	4.3%	14.3%	29.8%	41.1%	51.5%

TABLE 15. Summary of MPD values for the sensitivity cases, showing the start year spawning biomass in 2001 compared to B_{eq} (which is a proxy for B_0), the estimated size of the 1991 year class, and the estimated constant annual yield (CAY).

Sensitivity cases	SB_{eq} (10^3 mt)	SB_{2001} (10^3 mt)	$N_{2,1993}$ (10^6)	SB_{2001} (%SB_{eq})	CAY (10^3 t)
Base case	219	121	740	55%	20.8
Include CPUE	207	100	690	48%	17.2
Free $M (= 0.159)$	244	124	570	51%	19.2
$M = 0.15$	245	114	528	47%	17.7
$M = 0.25$	258	205	1234	79%	38.3
Absolute survey	223	123	735	55%	21.1
No catch-at-age	190	132	749	69%	22.7
No acoustic data	161	16	495	10%	2.8
Recruitment SD $= 1.5$	244	163	812	67%	28.0
Catch-at-age weight $= 10$	222	130	708	59%	22.4

TABLE 16. Estimates of constant annual yield (CAY) for the base case, obtained from the maximum of the posterior distribution, the 5%, 50% and 95%-iles of the posterior distributions, and the mean of the posterior distribution. The ratio of the start season spawning biomass in 2001 to that in 1991 is also given.

Base case estimates	SB_{1991} (10^3 mt)	SB_{2001} (10^3 mt)	SB_{2001} (%SB_{1991})	CAY (10^3 mt)
MPD estimate	48	121	253%	20.8
5% lower bound	40	76	189%	13.1
50% median of posterior	48	172	356%	29.6
95% upper bound	63	428	683%	73.6
Mean of the posterior	49	202	408%	34.7