

**Southern blue whiting (*Micromesistius australis*) stock  
assessment for the Bounty Platform for 2009–10**

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## EXECUTIVE SUMMARY

**Dunn, A.; Hanchet, S.M (2011). Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform for 2009–10.**

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This report documents the development of a stock assessment of the southern blue whiting Bounty Platform stock for the period 1990–2010 using catch history, proportion-at-age, and acoustic survey data up to and including the 2009 season. The primary data sources on abundance were the R.V. *Tangaroa* wide area acoustic surveys carried out from 1993 to 2001 and the industry vessel aggregation acoustic surveys carried out from 2004 to 2009, but the age data were also informative. The main information on recent stock size came from the aggregation surveys. Estimates of adult biomass from these surveys showed a 7-fold increase from 2006 to 2007 followed by a 4-fold decrease to 2009. The age data showed that a strong year class spawned in 2002 had begun to recruit into the fishery by 2006 and was likely to be responsible for the large increase seen in the acoustic surveys. The large decline in biomass in 2009 could not be explained by changes in population abundance due to fishing or natural mortality and it was assumed that the acoustic survey that year had failed to adequately survey the population.

Recent stock assessments which have attempted to fit the series of local area aggregation surveys were unable to reconcile the very sharp increase in adult biomass seen through the series with the observed proportions-at-age in the commercial fishery. In this assessment we were able to fully reconcile these conflicting data sources only by freeing up assumptions of constant catchability between the aggregation surveys, by treating the proportion-at-age data as three separate fisheries, and by having priors linking the acoustic catchability between the wide-area and aggregation surveys. One of the key issues with the assessment has been the treatment of the aggregation surveys, when the overall proportion of the adult biomass sampled by each survey is unknown.

There is little doubt that the 2002 year class is one of the strongest year classes seen in the southern blue whiting fishery. However, the actual size of it, and therefore the size of the current biomass and associated yields are extremely uncertain. The four model runs provided a range of possible estimates of  $B_{2009}$  ranging from 82 000 to 150 000 t. Although the MPD fits for all the runs looked reasonable, the MCMC trace diagnostics and autocorrelation lag plots suggested problems in some models and in other models the adult acoustic  $q$  were higher than might be considered plausible. Therefore, there is no clear indication of which model may be more likely.

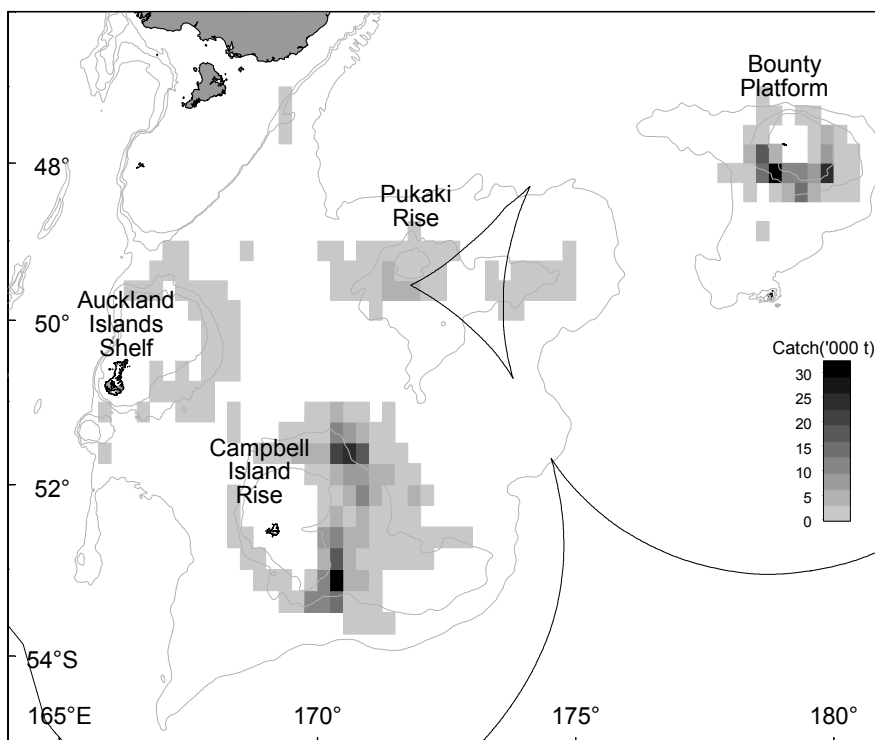
Since this modelling work was completed, an additional aggregation survey was carried out on the Bounty Platform in August 2010. Two snapshots were completed during the survey which appeared to fully cover the spawning aggregation. The estimate of adult biomass from the two snapshots was similar to that recorded for 2009. Reasons for the much lower observed biomass estimates from the surveys in 2009 and 2010 compared with 2007 and 2008 were explored, and included changes in survey methodology, equipment (including calibration), and changes in timing and extent of survey coverage. No reason for these low estimates was found. Given the low biomass estimates in 2009 and 2010, we therefore conclude that the estimates of current biomass calculated from the model are likely to be biased high. Further, we note that some of the model assumptions (e.g., the assumption of a constant rate of natural mortality or the priors on the acoustic surveys for 2007–2009) will need to be investigated to resolve this inconsistency.

## 1. INTRODUCTION

Southern blue whiting are almost entirely restricted in distribution to sub-Antarctic waters. They are dispersed throughout the Campbell Plateau and Bounty Platform for much of the year, but during August and September they aggregate to spawn near the Campbell Islands, on Pukaki Rise, on Bounty Platform, and near Auckland Islands over depths of 250–600 m (Figure 1). During most years fish in the spawning fishery range between 35 and 50 cm fork length (FL), although occasionally smaller size classes of males (29–32 cm FL) have been observed in the catch (Hanchet & Dunn 2010).

Commercial fishing has been concentrated on the Campbell Island Rise and, to a lesser extent, the Bounty Platform. The Pukaki Rise and Auckland Islands have been generally smaller fisheries, with much lower annual small catches compared with the Campbell Island Rise and Bounty Platform fisheries (Hanchet & Dunn 2010).

Wide area acoustic surveys using R.V. *Tangaroa* and assessments of the Bounty Platform stock were carried out in alternate years up until about 2002 (e.g., Hanchet et al. 2002, Hanchet et al. 2003). At that time, acoustic indices and subsequent assessments of the Bounty stock suggested that the spawning stock biomass had declined to a relatively low level. The catch limit was cut to 8000 t in 2000–01 and further to 3500 t in 2002–03. Because of the low catch limit, the value of the fishery was too low to be able to afford further R.V. *Tangaroa* acoustic surveys and the time series was discontinued (Hanchet & Dunn 2010). A new time series of local area aggregation surveys using industry vessels was initiated in 2004, and additional acoustic surveys were completed in 2006, 2007, 2008, and 2009 using industry vessels (Hanchet & Dunn 2010).



**Figure 1: Relative total density of the commercial catch of southern blue whiting by location, TCEPR data 1990–2009.**

A stock assessment for southern blue whiting on the Bounty Platform using the acoustic estimate from the aggregation survey was made in 2004 and suggested a stock status similar to that obtained in previous assessments (Hanchet 2005). However, the aggregation surveys in

2007 and 2008 showed a large increase in biomass, believed to be the result of a very strong year class recruiting to the fishery. Attempts to fit the large increase in biomass using the then existing stock assessment modelling assumptions were largely unsuccessful (Hanchet & Dunn 2009a, 2009b). This was primarily because of conflicts between the acoustic indices and the relative proportions at age in the commercial catch-at-age data set arising from assumptions of constant growth, constant selectivity, and constant aggregation survey catchability.

This report documents the development of a revised stock assessment of the Bounty Platform using the data up to and including the 2009 season using the wide area (R.V. *Tangaroa*) and local area aggregation acoustic survey indices and commercial catch proportions-at-age data. In developing this assessment it was necessary to free up some of the assumptions of constant catchability and constant selectivity over time due to conflicts in observations both within and between the local area aggregation estimates and the proportions-at-age data.

This report is in fulfilment of the Ministry of Fisheries Project SBW2008/01 (To carry out stock assessments of southern blue whiting (*Micromesistius australis*) including estimating biomass and sustainable yields) Objective 2 (To update the stock assessment of the Bounty Platform stock, including estimating biomass and sustainable yields).

## 2. METHODS

Preliminary model runs did not provide a satisfactory fit to either the aggregation acoustic survey estimates or the proportion-at-age data. Hence, the development of the assessment focused on (i) freeing up the aggregation survey catchability between years so that the large variation in biomass estimates between years could be adequately fitted; (ii) constraining the aggregation survey estimates to have a similar  $q$  to that of the adult (4+) biomass from the wide area surveys; (iii) allowing the fishing selectivity to vary over time to allow for the conflict between the observations from the aggregation survey biomass estimates, and (iv) resolving computational difficulties when considering the 2002 year class estimate in the calculation of virgin biomass. As we note in the discussion, the resulting stock assessments are likely to be highly dependent on these underlying assumptions, possibly over-parameterised, and the uncertainty may not be adequately reflected in the quantitative outputs.

### 2.1 Population dynamics and model structure

A two-sex, single stock and area Bayesian statistical catch-at-age model for the Bounty Platform southern blue whiting stock was implemented in CASAL (Bull et al. 2009). The model partitioned the stock into two sexes with age groups 2–11, with a plus group at age 11, and was run for the years 1979 to 2009. Five year projections were run for the years 2010–2014. The annual cycle was partitioned into two time steps (Table 1). In the first time step (nominally the non-spawning season), 90% of natural mortality was assumed to have taken place. In the second time step (spawning season), fish ages were incremented; the 2-year-olds were recruited to the population, which were then subjected to fishing mortality and the remaining 10% of natural mortality. A two sex model was used because there are significant differences observed between males and females in both the proportions at age in the commercial catch for fished aged 2–4 (see later) and their mean size at age (Hanchet & Dunn 2010).

Southern blue whiting exhibit large inter-annual differences in growth, presumably caused by local environmental factors but also closely correlated with the occurrence of the strong and weak year classes. Hence, we do not use a standard von Bertalanffy growth curve to determine the mean size-at-age of fish in the model, but rather an empirical size-at-age matrix (Table 2). The size-at-age matrix was derived by qualitatively reviewing the empirically

estimated mean sizes-at-age from the commercial catch-at-length and -age data (Hanchet & Dunn 2010). Missing estimated mean sizes in the matrix were inferred from the relative size of their cohort and the mean growth of similar ages in other years; cohorts with unusually small or large increments were similarly adjusted.

The mean size-at-ages in the future years were assumed for projections. The mean size in 2010 was calculated by adding the observed mean growth increment from 1990 to 2009 to each age class in 2009 to determine their expected sizes in 2010, with the mean size of aged 2 fish in 2010 assumed to be equal to the mean of the annual mean sizes of aged 2 fish from 1990 to 2009. By iteratively applying the above algorithm, the mean sizes for the years 2011–2014 were determined (Table 2).

Lengths-at-age were converted to weights-at-age in the model using the length-weight relationship given by Hanchet (1991), i.e., assuming the relationship  $\text{weight} = a \times \text{length}^b$  for length in centimetres and weight in kilograms, the parameters  $a = 0.00515$  and  $0.00407$ , and  $b = 3.092$  and  $3.152$  were assumed for males and females respectively.

In general, southern blue whiting are assumed to be fully or almost fully selected by the fishery at either age four or five and not vulnerable to fishing at age one. We assumed that fishing selectivities were logistic by sex, and that the maximum exploitation rate ( $U_{\max}$ ) was 0.8. Further, in order to include potential changes in selectivity either as a function of age or sex, we investigate both age-based selectivities with an annual shift parameter, or size-based selectivities with an annual shift parameter. The choice of models with either age- or size-based selectivities are described later.

In previous models of southern blue whiting on the Bounty Platform (e.g., Hanchet & Dunn 2009a), fish available to the fishery were all assumed to be mature and spawning, with all of these fish equally likely to be vulnerable to fishing (i.e., a fishing selectivity was assumed that was equal to one for all mature fish). In the models presented here, we disentangled the estimates of the maturity ogive from the fishing selectivity. Hence, we assume a fixed proportion of fish at age and sex mature (see Figure 2), and estimate a logistic shaped fishing selectivity for males and females respectively. The stock recruitment relationship was assumed to be Beverton-Holt with a steepness of 0.9, with the proportion of males at recruitment (at age 2) assumed to be 0.5 of all recruits.

In previous models (Hanchet & Dunn 2009a), three different starting conditions were explored as different sets of model runs. In the first (labelled *Cinit*), the model was started in 1990 and the numbers in the population at the start of the model were estimated for each age and sex separately (i.e., described as a Cinitial starting state by Bull et al. 2009). For the other two starting conditions, the models were started at the beginning of the known fishery in 1971 and (i) assumed that the population in 1971 was at the mean equilibrium unexploited level (labelled  $B_0$ ), or (ii) assumed that the population in 1971 was not at equilibrium, although it still had an equilibrium age structure (labelled *Binit*). In all three cases, the equilibrium biomass that would occur with average recruitment and no fishing is described as  $B_0$ .

In this report, we investigate only one of these options, the *Cinit* model. Further, we constrain the estimates of the initial age structure so that the number of males within each age class was equal to the number of females within that age class. However, in developing the models for southern blue whiting on the Bounty Platform, we found that in the exploratory model runs the estimates of the very large year class observed in 2002 were strongly confounded with model estimates of the overall mean recruitment, equilibrium ( $B_0$ ), and initial abundance (*Cinit*). To resolve this issue, the mean year class strength constraint was modified to exclude the 2002 year class, i.e., we replaced the constraint that the mean of the relative year class strengths for 1988–2006 equal one with the constraint that the mean of the relative year class strengths for 1988–2001 and 2003–2006 combined equal one. This modification removed

most of the confounding between key parameters, and resulted in much more numerically stable models.

Note that in other, similar assessment models, the equilibrium unexploited spawning biomass ( $B_0$ ) is typically defined as being equal to the spawning biomass that there would have been if the mean relative year class strength was equal to one over some defined period and there was no fishing (see Bull et al. (2009) for rationale). Here, as we ignore the 2002 year class in the averaging process, we define the equilibrium unexploited spawning biomass as being equal to the spawning biomass that there would have been if the mean relative year class strength was equal to one over the period 1998–2001 and 2003–2006 combined with no fishing.

This modification has a number of consequences. First, projections that assume a mean relative year class strength of one ignore the possibility of a very strong year class like that observed in 2002, and second, biomass reference points will have a lower value than otherwise i.e., 20%  $B_0$  will have a lower absolute value with this assumption than it would have if the 2002 year class was included in the calculations.

**Table 1: Annual cycle of the stock model, showing the processes taking place at each step, and the available observations. Fishing mortality ( $F$ ) and natural mortality ( $M$ ) that occur within a time step occur after all other processes.  $M$ , proportion of  $M$  occurring in that time step.**

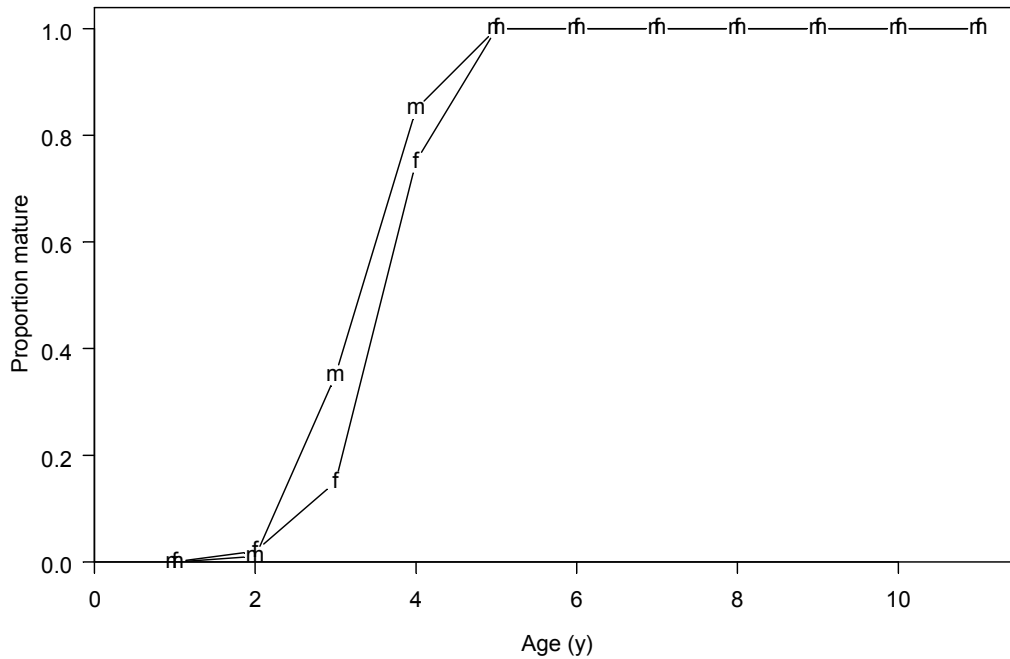
Period	Process	M	Length at age	Observations
1. Nov–Aug	Natural mortality ( $M$ )	0.9	–	–
2. Sep–Oct	Age, recruitment, fishing mortality ( $F$ ), and $M$	0.1	Growth matrix	Proportion at age, and abundance indices

**Table 2a: Assumed mean length (cm) at age for male southern blue whiting aged 2–11+, 1990–2009, and the assumed mean length at age for projections, 2010–2014 (grey highlight).**

Year	2	3	4	5	6	7	8	9	10	Age 11+
1990	26.8	32.3	35.6	38.0	42.6	47.1	45.6	43.6	46.5	48.1
1991	29.0	32.3	35.3	39.0	43.0	45.8	46.0	47.0	44.8	48.8
1992	24.0	32.7	35.6	39.6	40.8	45.0	47.1	46.9	47.4	49.2
1993	28.0	27.1	35.8	38.0	40.0	42.6	46.0	48.0	47.6	48.4
1994	27.7	32.1	36.0	38.3	40.7	43.8	43.9	47.0	47.7	49.2
1995	28.8	31.1	35.4	37.3	40.3	41.9	43.8	45.3	49.0	48.6
1996	25.4	32.2	34.1	37.8	38.0	41.3	43.7	44.9	46.0	48.7
1997	27.4	31.4	34.9	36.4	39.1	41.0	42.7	44.4	46.2	50.7
1998	28.2	30.8	32.5	36.1	37.7	40.7	42.0	45.1	46.2	47.4
1999	28.8	32.0	34.9	35.3	38.9	40.0	42.2	43.0	45.0	46.9
2000	26.8	33.1	35.4	38.9	39.7	41.0	42.9	44.2	45.0	45.6
2001	28.7	32.5	36.2	38.5	41.5	41.0	42.0	42.7	47.0	49.6
2002	27.3	32.9	36.1	39.2	41.1	41.3	42.3	43.4	46.8	49.1
2003	32.8	30.9	35.9	38.4	41.2	43.1	42.1	43.6	44.6	48.5
2004	25.0	34.0	37.8	40.4	41.4	42.9	45.1	47.0	45.0	45.3
2005	28.0	29.0	36.0	39.8	41.0	42.4	42.7	44.0	45.2	46.7
2006	28.9	30.8	32.3	37.0	41.4	42.7	43.6	44.4	45.4	46.4
2007	28.5	30.0	33.6	34.5	38.0	42.8	44.8	44.5	47.1	45.4
2008	30.0	32.0	33.0	34.5	36.2	39.0	44.9	45.3	46.5	47.4
2009	28.0	33.9	35.0	35.1	36.3	37.9	39.8	46.4	46.6	48.2
2010	27.9	31.7	37.3	37.5	37.5	38.5	39.4	41.2	47.6	48.3
2011	27.9	31.7	35.2	39.9	39.8	39.7	40.0	40.8	42.5	49.2
2012	27.9	31.7	35.1	37.7	42.2	42.1	41.2	41.4	42.0	44.1
2013	27.9	31.7	35.1	37.6	40.0	44.4	43.6	42.6	42.6	43.7
2014	27.9	31.7	35.1	37.6	39.9	42.2	45.9	44.9	43.8	44.2

**Table 2b: Assumed mean length (cm) at age for female southern blue whiting aged 2–11+, 1990–2009, and the assumed mean length at age for projections, 2010–2014 (grey highlight).**

Year	Age									
	2	3	4	5	6	7	8	9	10	11+
1990	26.5	30.8	38.2	43.7	45.0	47.1	49.6	50.0	53.6	53.4
1991	25.6	33.2	37.3	41.7	46.3	45.8	49.0	50.5	52.0	54.0
1992	29.1	33.8	37.3	41.8	43.8	47.4	50.6	50.0	51.5	52.5
1993	27.3	37.0	37.6	40.5	43.2	46.0	49.8	51.8	52.4	53.9
1994	28.5	33.8	39.0	41.0	43.1	46.3	48.2	51.5	52.5	53.2
1995	31.0	32.6	37.7	41.0	44.4	45.2	48.7	49.9	52.6	54.0
1996	25.1	31.4	36.0	40.2	43.0	45.6	46.2	48.9	50.6	53.2
1997	27.5	33.3	36.4	38.2	42.5	45.0	48.3	48.4	50.2	53.5
1998	29.6	30.9	35.5	39.4	39.9	44.2	46.1	48.4	49.5	53.1
1999	30.0	34.0	35.6	37.8	40.9	42.9	45.7	47.6	48.9	51.4
2000	27.1	34.0	36.6	40.3	40.8	44.5	45.2	48.4	48.9	53.7
2001	27.2	35.8	38.5	42.1	42.2	43.5	45.0	47.3	49.2	53.2
2002	28.2	34.7	38.7	42.4	43.7	45.2	47.0	48.9	50.9	55.0
2003	30.9	35.8	38.4	42.3	44.4	45.7	47.5	49.0	50.1	53.2
2004	25.1	35.0	39.6	42.6	44.0	46.0	46.6	48.9	49.7	51.2
2005	28.2	29.9	37.0	42.0	44.2	44.9	46.9	49.0	48.9	51.0
2006	29.0	30.8	33.4	39.0	44.2	45.5	47.2	48.4	51.2	50.6
2007	27.1	31.8	34.0	36.3	40.0	44.6	48.1	48.9	49.4	52.2
2008	28.2	32.3	34.6	36.4	38.1	41.0	47.8	48.9	49.0	52.0
2009	28.2	33.3	35.8	37.9	38.1	39.9	43.1	49.3	50.2	51.2
2010	28.0	33.5	36.9	39.3	40.2	40.3	42.4	45.0	50.7	52.4
2011	28.0	33.2	37.1	40.4	41.5	42.4	42.8	44.3	46.4	52.9
2012	28.0	33.2	36.9	40.6	42.7	43.8	44.9	44.7	45.7	48.6
2013	28.0	33.2	36.9	40.3	42.8	44.9	46.3	46.8	46.1	47.9
2014	28.0	33.2	36.9	40.3	42.6	45.1	47.4	48.1	48.1	48.3



**Figure 2: Assumed proportions mature of southern blue whiting for males (m) and females (f), Bounty Platform.**



## 2.2 Observations

### 2.2.1 Wide area acoustic surveys

Acoustic biomass estimates of southern blue whiting available on and around the Bounty Platform during the fishing season are available from a wide area survey series conducted by the research vessel *Tangaroa* in 1993–1996, 1997, 1999, and 2001 (Hanchet & Dunn 2010).

We assume that the wide area survey acoustic biomass estimates were of southern blue whiting aged 2, 3, and 4+ (Table 3), and that these were relative estimates of mid-season biomass (i.e., after half the catch has been removed), with a c.v. equal to sampling c.v. estimated from the survey. The wide area acoustic biomass observations were fitted using a lognormal likelihood, i.e.,

$$-\log(L) = \sum_{i=1}^n \left( \log(\sigma_i) + 0.5 \left( \frac{\log(O_i/qE_i)}{\sigma_i} + 0.5\sigma_i \right)^2 \right)$$

$$\text{where } \sigma_i = \sqrt{\log(1+c_i^2)}$$

where  $O_i$  are the observed biomass estimates at time  $i$  with c.v.s  $c_i$ ,  $E_i$  are the model expected biomasses at time  $i$  and  $q$  is the catchability constant for the biomass series.

**Table 3: R.V. *Tangaroa* age 1, 2, 3, and 4+ acoustic biomass estimates for the Bounty Platform using the revised target strength and sound absorption coefficient, 1993–2001 (Grimes et al. 2007).**

Year	Age 1		Age 2		Age 3		Age 4+	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	29 057	0.23	11 347	0.25	777	0.37	47 087	0.64
1994	299	0.81	9 082	0.28	36 445	0.25	20 844	0.25
1995	155 460	0.37	7 108	0.32	7 874	0.34	23 480	0.24
1997	5 054	0.39	7 274	0.36	30 668	0.41	31 929	0.32
1999	993	0.57	1 134	0.33	5 618	0.62	34 194	0.73
2001	379	0.16	4 669	0.23	7 261	0.19	16 396	0.36

### 2.2.2 Local area aggregation acoustic surveys

A time series of southern blue whiting local area aggregation surveys has been carried out from industry vessels fishing the Bounty Platform (O'Driscoll 2011). From 2004 to 2009, industry vessels opportunistically collected acoustic data from the Bounty Platform fishing grounds using a random stratified survey design over an ad-hoc area that encompassed an aggregation of southern blue whiting. The aggregation surveys had mixed levels of success (O'Driscoll 2011). Acoustic data collected in 2005 could not be used because of acoustic interference from the scanning sonar used by the vessel for searching for fish marks and inadequate survey design (O'Driscoll 2011). There was also some concern that the surveys in 2006 and 2009 may not have sampled the entire aggregation as fish marks extended beyond the area being surveyed on some transects (O'Driscoll 2011).

We assume that the local area aggregation survey estimates were relative estimates of mid-season spawning stock biomass (i.e., after half the catch has been removed), with a c.v. equal to the sampling c.v. estimated from the survey. However, as the coverage was likely to have been different in each year, the series was assumed to be a time series with non-constant catchability, and hence we assume that the catchability coefficient ( $q$ ) for each year was an

independent parameter in the model. In order to use these survey estimates and allow the biomass estimates to provide some information to the model, we assume that the local area aggregation survey catchability coefficients were related to the wide area acoustic survey estimates via a  $q$  ratio prior (see section 6.5.7 of Bull et al. (2009) for detail). Hence we specified a prior distribution on the ratio of catchabilities for the local area aggregation survey and the wide area surveys, with the ratio prior assumed to be lognormally distributed and parameterised by a mean and c.v. (see also 2.3.1).

The local area aggregation survey biomass observations were fitted using a lognormal likelihood, i.e.,

$$-\log(L) = \sum_{i=1}^n \left( \log(\sigma_i) + 0.5 \left( \frac{\log(O_i/q_i E_i)}{\sigma_i} + 0.5\sigma_i \right)^2 \right)$$

$$\text{where } \sigma_i = \sqrt{\log(1 + c_i^2)}$$

where  $O_i$  are the observed biomass estimates at time  $i$  with c.v.s  $c_i$ ,  $E_i$  are the model expected biomasses at time  $i$  and  $q_i$  is the catchability constant for the individual local area aggregation biomass observation.

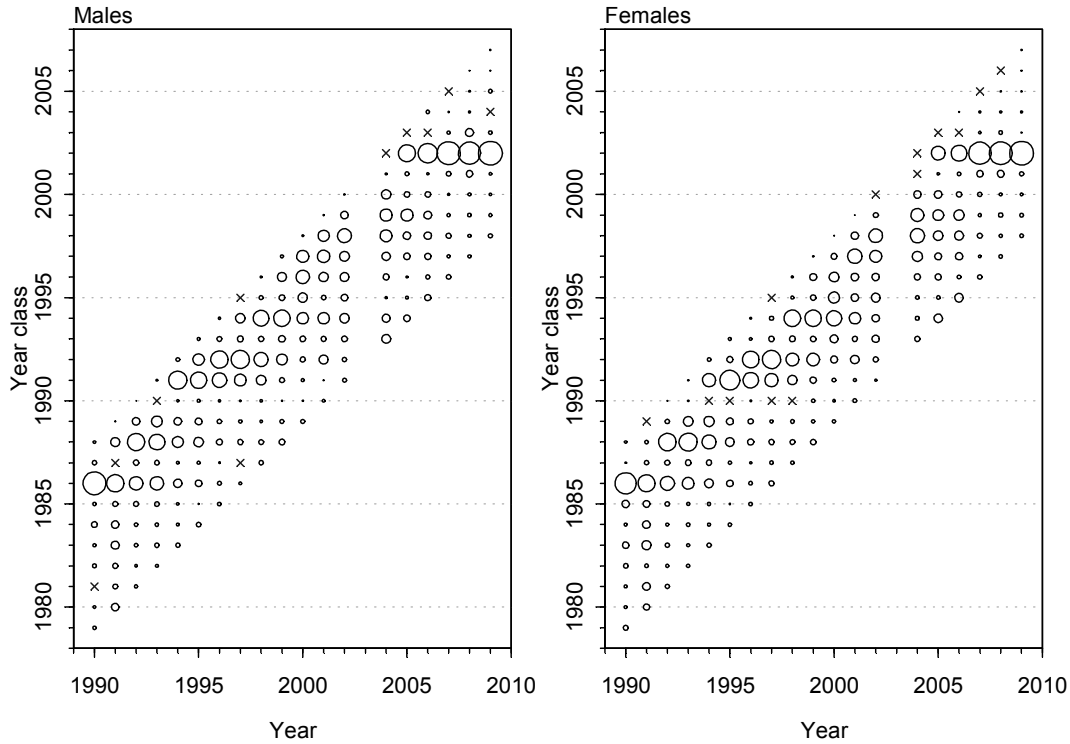
### 2.2.3 Proportions-at-age in the catch

Catch-at-age observations by sex were available from the commercial fishery for 1990 to 2009 from observer data (Figure 3). Commercial catch-at-age data were fitted to the model as proportions-at-age by sex, where associated c.v.s by age were estimated using the NIWA catch-at-age software by bootstrap (Bull & Dunn 2002). The catch proportions-at-age data were fitted to the modelled proportions-at-age composition using a multinomial likelihood, i.e.,

$$-\log(L) = -\log(N!) + \sum_i \left[ \log((NO_i)!) - NO_i \log(E_i) \right]$$

where  $O_i$  are the observed proportions-at-age  $i$ ,  $E_i$  are the model expected proportions-at-age  $i$ , and  $N$  is the effective sample size. Proportions-at-age data were derived from the aged otoliths collected by observers and the length frequency of the catch. Hanchet & Dunn (2010) described the catch-at-age data available for the assessment models from 1990. The derivation of the assumed multinomial sample sizes for the proportions-at-age data is described below.

Ageing error was ignored in the proportions-at-age data as errors in ageing for southern blue whiting are believed to be very low.



**Figure 3: Commercial catch proportions at age for the Bounty Platform stock by sex and year class, 1990–2009 for ages 2–11+. Symbol area proportional to the proportions-at-age within the sampling event.**

### 2.3 Model estimation

The model parameters were estimated by minimising an objective function, which is the sum of the negative log-likelihoods from the data, negative-log priors (in a Bayesian analysis), and penalties that constrain the parameterisations, i.e., the objective function in a Bayesian analysis for  $\mathbf{p}$ , the vector of the free parameters,  $L$  the likelihood function, and  $O_i$  the  $i$ th observation was

$$\text{Objective}(\mathbf{p}) = -\sum_i \log[L(\mathbf{p} | O_i)] - \log[\theta(\mathbf{p})]$$

where  $\theta$  is the joint prior (and penalty) density of the parameters  $\mathbf{p}$ . The observations, likelihoods, penalties, and priors are described later.

Initial model fits were evaluated at the maximum of the posterior density (MPD) and by investigating model fits and residuals. At the MPD, the approximate covariance matrix of the free parameters was calculated as the inverse of the approximation to the Hessian, and the corresponding correlation matrix also calculated.

To estimate the joint posterior distribution of the parameters in a Bayesian analysis, CASAL uses a straightforward implementation of the Metropolis algorithm (Gelman et al. 1995, Gilks et al. 1998) to execute the Monte Carlo Markov Chain (MCMC). The Metropolis algorithm attempts to draw a sample from a Bayesian posterior distribution, and calculates the posterior density  $\pi$ , scaled by an unknown constant. The algorithm generates a ‘chain’ or sequence of values. Typically the beginning of the chain is discarded and every  $n$ th element of the remainder is taken as the posterior sample. The chain is produced by taking an initial point  $x_0$  and repeatedly applying the following rule, where  $x_i$  is the current point; (i) draw a candidate

step  $s$  from a proposal distribution  $J$ , which should be symmetric, i.e.,  $J(-s)=J(s)$ , (ii) calculate  $r=\min(\pi(x_i+s)/\pi(x_i),1)$ , and (iii) let  $x_{i+1}=x_i+s$  with probability  $r$ , or  $x_i$  with probability  $1-r$ .

A point estimate (i.e., the MPD) was produced, along with the approximate covariance matrix of the parameters (as the inverse Hessian — see Bull et al. (2009) for more detail), and used as the starting point for the chain.

MCMCs were estimated using a burn-in length of  $1 \times 10^6$  iterations, with every 10 000<sup>th</sup> sample taken from the next  $1 \times 10^7$  iterations (i.e., a systematic sample of length 1000 was taken from the Bayesian posterior). Chain diagnostic plots, autocorrelation estimates, and single chain convergence tests of Geweke (1992) and Heidelberger & Welch (1983) stationarity and half-width were used to determine evidence of non-convergence. The tests used a significance level of 0.05 and the diagnostics were calculated using the Bayesian Output Analysis software (Smith 2003).

### 2.3.1 Prior distributions and penalties

In general, the assumed prior distributions used in the assessment were intended to be non-informative with wide bounds (Table 4). The exceptions to this were the priors and penalties on biomass catchability coefficients and on relative year class strengths. The prior assumed for the relative year class strengths was lognormal, with mean 1.0 and c.v. 1.3, for all year classes except for the 2002 year class. To allow for the possibility that the 2002 year class was much stronger than average, the lognormal prior c.v. was modified to be less constraining and set to 10.

A log-normal prior was used for the wide area acoustic survey catchability coefficient with mean 1.0 and c.v. 0.2. The prior used for the wide area acoustic survey catchability coefficient was originally obtained using the approach of Cordue (1996), and was detailed by Hanchet (2002). Uncertainty over various factors, including mean target strength, acoustic system calibration, target identification, shadow or dead zone correction, and areal availability were included within the derivation of the prior. That approach suggested a mean of 1.4 and c.v. 0.2 with bounds 0.1–2.8. Following the recalibration of the acoustic estimates with revised estimates of the target strength relationship and sound absorption coefficients, the Middle Depths Working Group revised the prior to have mean 1.0 with c.v. 0.2, and retained the same bounds.

Priors for the local area aggregation surveys were non-informative, but a  $q$  ratio prior was added to encourage the estimates to be specific ratios of the wide area acoustic catchability coefficient. The specification of the  $q$  ratio priors was based on the assumption that (i) the wide area surveys covered all of the vulnerable population, (ii) the 2004, 2007, and 2008 local area aggregation surveys also covered all of the vulnerable population, and (iii) the 2006 and 2009 surveys missed a large, but unknown, proportion of the vulnerable population.

Two alternative model scenarios were implemented. The first assumed a prior that strongly constrained the catchability coefficients of the 2004, 2007, and 2008 surveys to be very like the catchability coefficient of the wide area surveys (tight prior), and the second where this assumption was relaxed to be less constraining (diffuse prior). The values of the prior assumed for the  $q$  ratio for each survey and for the two scenarios are shown in Figure 4 and given in Table 5.

The catchability constants were assumed to be a nuisance parameter, i.e., the value of the  $q$  was chosen that minimised the objective function, calculated algebraically (see Bull et al. (2009) for more detail). A lognormal likelihood was used for the biomass indices, with observations  $O_i$ , c.v.  $c_i$ , and expected values  $qE_i$  is,

$$-\log(L) = \sum_{i=1}^n \left( \log(\sigma_i) + 0.5 \left( \frac{\log(O_i/qE_i)}{\sigma_i} + 0.5\sigma_i \right)^2 \right)$$

where  $\sigma_i = \sqrt{\log(1 + c_i^2)}$ .

Penalty functions were used to constrain the model so that any combinations of parameters that did not allow the historical catch to be taken were strongly penalised. A small penalty was applied to encourage the estimates of year class strengths to average to 1.

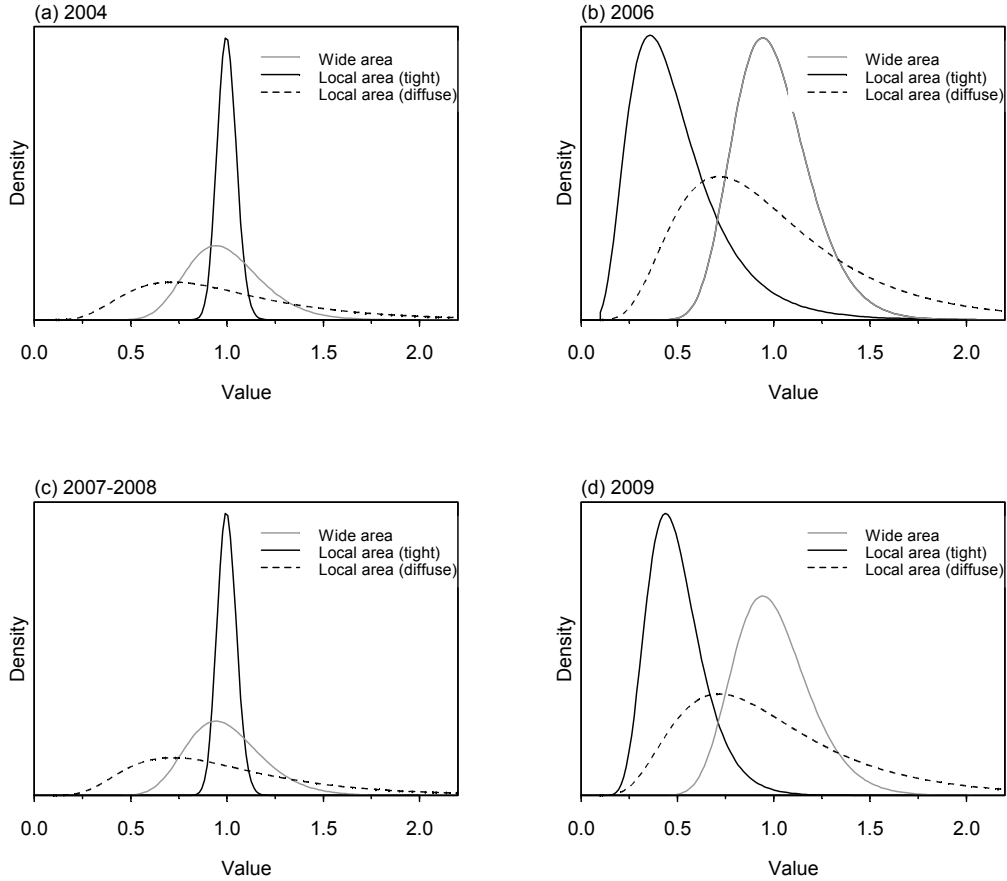
**Table 4: The distributions, priors, and bounds assumed for the various parameters being estimated ( $q$  ratio priors are given in Table 5).**

Parameter	N	Distribution	Values		Bounds	
			Mean	c.v.	Lower	Upper
$B_0$	1	Uniform-log	–	–	20 000	250 000
Initial population (by sex)	10	Uniform	–	–	2e2	2e9
Male fishing selectivity	2	Uniform	–	–	1	20
Female fishing selectivity	2	Uniform	–	–	0.02	20
Selectivity shift parameters	3	Uniform	–	–	-20	20
Year class strength	19	Lognormal	1.0	1.3 <sup>1</sup>	0.001	100
Wide area catchability 4+ $q$	1	Lognormal	1.0	0.2	0.1	2.8
Wide area catchability 3+ $q$	1	Uniform	–	–	0.1	2.8
Wide area catchability 2+ $q$	1	Uniform	–	–	0.1	2.8
2004 local area catchability $q$	1	Uniform	–	–	0.1	2.8
2006 local area catchability $q$	1	Uniform	–	–	0.1	2.8
2007 local area catchability $q$	1	Uniform	–	–	0.1	2.8
2008 local area catchability $q$	1	Uniform	–	–	0.1	2.8
2009 local area catchability $q$	1	Uniform	–	–	0.1	2.8

Note 1: Except for 2002. Here the c.v. = 10.

**Table 5: Aggregation survey biomass estimates for the Bounty Platform (with the revised target strength and sound absorption coefficient) and the assumed  $q$  ratio prior, 2004–2009.**

Year	Biomass	c.v.	Reference	$q$ ratio prior			
				Tight prior		Diffuse prior	
				$\mu$	c.v.	$\mu$	c.v.
2004	13 473	0.69	(O'Driscoll 2011)	1.00	0.05	1.00	0.50
2006	21 765	0.12	(O'Driscoll 2011)	0.50	0.50	0.50	0.50
2007	159 589	0.19	(O'Driscoll 2011)	1.00	0.05	1.00	0.50
2008	144 187	0.34	(O'Driscoll 2011)	1.00	0.05	1.00	0.50
2009	36 814	0.24	(O'Driscoll 2011)	0.50	0.30	0.50	0.30



**Figure 4: The priors assumed for the wide area surveys (grey lines), and the assumed tight (solid lines) and diffuse (dashed lines)  $q$  ratio for the local area aggregation surveys for (a) 2004, (b) 2006, (c) 2007–2008, and (d) 2009.**

### 2.3.2 Process error and data weighting

Lognormal errors, with known c.v.s, were assumed for the relative biomass and proportions-at-age data. The c.v.s available for these data allow for sampling error only. However, additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance. The additional variance, termed process error, was estimated in each of the initial runs (MPDs) using all the available data. Process errors were estimated separately for the proportion-at-age data, and for the acoustic estimates from the wide area and local area aggregation surveys.

Estimates of the sample size for the proportions-at-age observations were made via a two-step process. First, the sample sizes were derived by assuming the relationship between the observed proportions,  $E_i$ , and estimated c.v.s,  $c_i$ , followed that for a multinomial distribution with unknown sample size  $N_j$ . The estimated sample size was then derived using a robust non-linear least squares fit of  $\log(c_i) \sim \log(P_i)$ . Second, estimates of the effective sample size,  $N_j'$ , by adding additional process error,  $N_{PE}$ , to the sample size calculated in (a) above, where,

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

i.e., from an initial MPD model fit, an estimate of the additional process error was made by solving the following equation for  $N_{PE}$ ,

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

where  $n$  was the number of multinomial cells,  $O_{ij}$  was the observed proportions for age class  $i$  in year  $j$ ,  $E_{ij}$  was the expected proportions,  $N_j$  was the effective sample size estimated in (a) above, and  $N_{PE}$  was the associated process error for that class of observations. Estimates of the additional process error for the models are described below.

Estimates of the process error c.v. for the biomass observations were made by fitting the process error within each MPD run, where the applied c.v.  $c'_i$  was determined from the process error  $c_{PE}$  and the observed c.v.s  $c_i$  by,

$$c'_i = \sqrt{c_i^2 + c_{PE}^2}.$$

However, in all models the estimated additional process error for the biomass estimates was zero.

### 3. RESULTS

#### 3.1 Exploratory models and model runs

Several exploratory model runs were investigated in order to determine the key aspects of the models that would need further investigation. Initially, we discuss two models. The first (labelled model 1.1) assumed a constant age-based fishing selectivity for the catch history, and the second assumed a constant size-based selectivity (labelled model 1.3). In considering the exploratory models, we focused on the fits to the acoustic biomass time series, fits to the proportions-at-age data, and the estimated relative year class strengths. Both models assumed that the additional process error for the commercial catch-at-age proportions was  $n=30$  (i.e., process error values were fixed and not estimated in the exploratory models).

For both of the exploratory models, the fits to the wide area and aggregation biomass indices appeared reasonable (Figure 5), and fits to most of the age data were also good. However, neither model was able to fit the age data for the 2005 and 2006 years (Figure 6). Both models suggested that the mean age of fish caught in 2005 and 2006 should be much lower than had been observed. The model estimates were consistent with the influx of a very strong 2002 year class (Figure 7) into the fishery in 2005 and 2006. However, the commercial catch proportions-at-age data suggested that the influx was not observed until at least 2007 (see Figure 3).

The evidence from the commercial catch-at-age proportions and the large increase in biomass observed in the acoustic biomass estimates lend weight to the belief of a very strong 2002 year class. The paucity of fish from this year class observed in 2005 and 2006 would suggest that many of the fish from this year class either failed to turn up in the fishery in those years or were not vulnerable to fishing in those seasons.

In order to model the possibility that the fishing selectivity had changed so that these fish were not available to the fishery, we considered a 'selectivity shift' extension to both models. Here we introduced an annual shift parameter into the fishing selectivity for years following the 2002 year class. The annual shift parameter maintained the same shape selectivity, but allowed the model to shift the selectivity to the right to reduce the expected proportion of the 2002 year class available to the fishery. Exploratory analysis suggested that while the mean

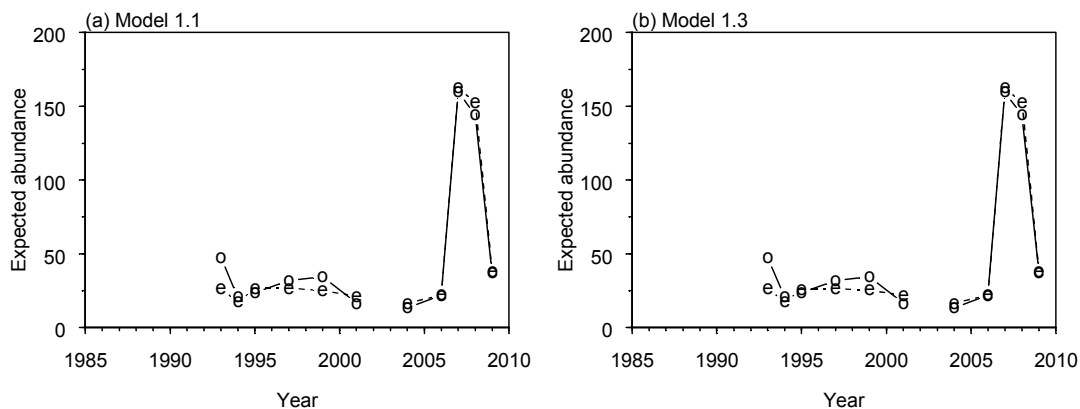
age fits from a model with a selectivity that had annual shift parameters for 2005–2006 might be sufficient, likelihood values and fits to the individual age data (not shown) suggested that a model with annual shift parameters that included the 2007 year as well substantially improved the model fits.

As a result of these investigations, we considered two main scenarios for modelling the Bounty Platform stock. The first assumed age-based selectivity ogives for the fishery, but with an annual shift parameter for the years 2005–2007. The second made the same assumptions for the model population structure and selectivity shifts, but assumed that the fishing selectivities were size-based.

Further, in order to investigate the impact of the  $q$  ratio prior assumption on the models outputs, we investigated ‘tight’ and ‘diffuse’ prior assumptions (Section 2.3.1). The first assumed a prior that strongly constrained the catchability coefficients of the 2004, 2007, and 2008 surveys to be very like the catchability coefficient of the wide area surveys (tight priors, Table 5), and the second where this assumption was relaxed to be less constraining (diffuse priors, Table 5). The model runs discussed are summarised in Table 6.

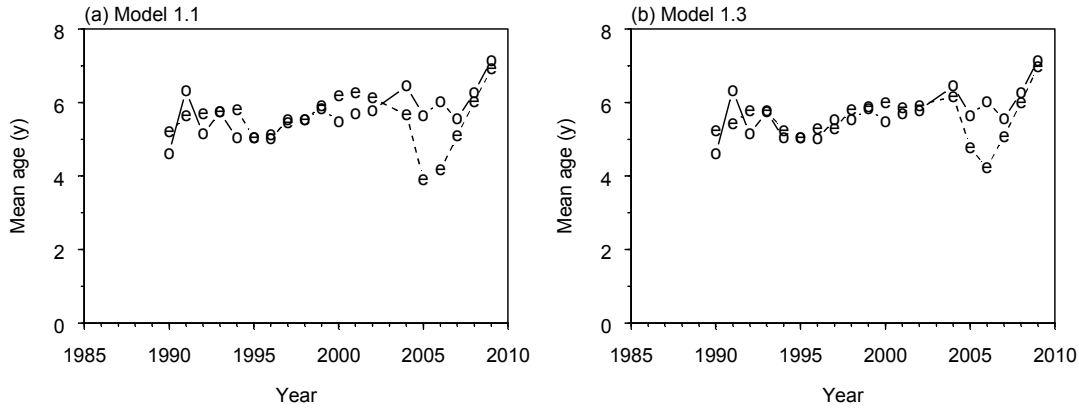
**Table 6: Model run labels and descriptions for the model runs.**

Model type	Label	Description
Exploratory models	1.1	Age-based fishing selectivity with ‘tight’ $q$ ratio priors (1 fishery)
	1.3	Size-based fishing selectivity with ‘tight’ $q$ ratio priors (1 fishery)
Final Models	3.4	Age-based fishing selectivity with ‘tight’ $q$ ratio priors (3 fisheries)
	3.6	Size-based fishing selectivity with ‘tight’ $q$ ratio priors (3 fisheries)
	4.4	Age-based fishing selectivity with ‘diffuse’ $q$ ratio priors (3 fisheries)
	4.6	Size-based fishing selectivity with ‘diffuse’ $q$ ratio priors (3 fisheries)

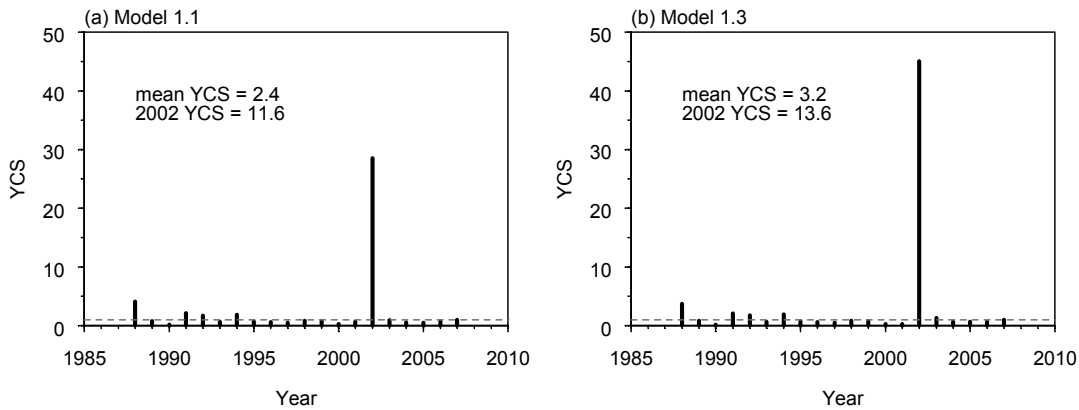


**Figure 5: Observed (o) and expected (e) fits to the wide area and local area aggregation biomass indices for the exploratory models with (a) age based selectivities (model 1.1), and (b) size-based selectivities (model 1.3).**





**Figure 6: Observed (o) and expected (e) mean ages for the exploratory models with (a) age based selectivities (model 1.1), and (b) size-based selectivities (model 1.3).**



**Figure 7: Estimated relative year class strengths for the exploratory models with (a) age based selectivities (model 1.1), and (b) size-based selectivities (model 1.3). Plots also show the mean of the year class strengths from the period 1988–2006 including the 2002 year class, and the equivalent 2002 year class multiplier assuming a mean of one for the period 1988–2006.**

### 3.2 MPD model fits

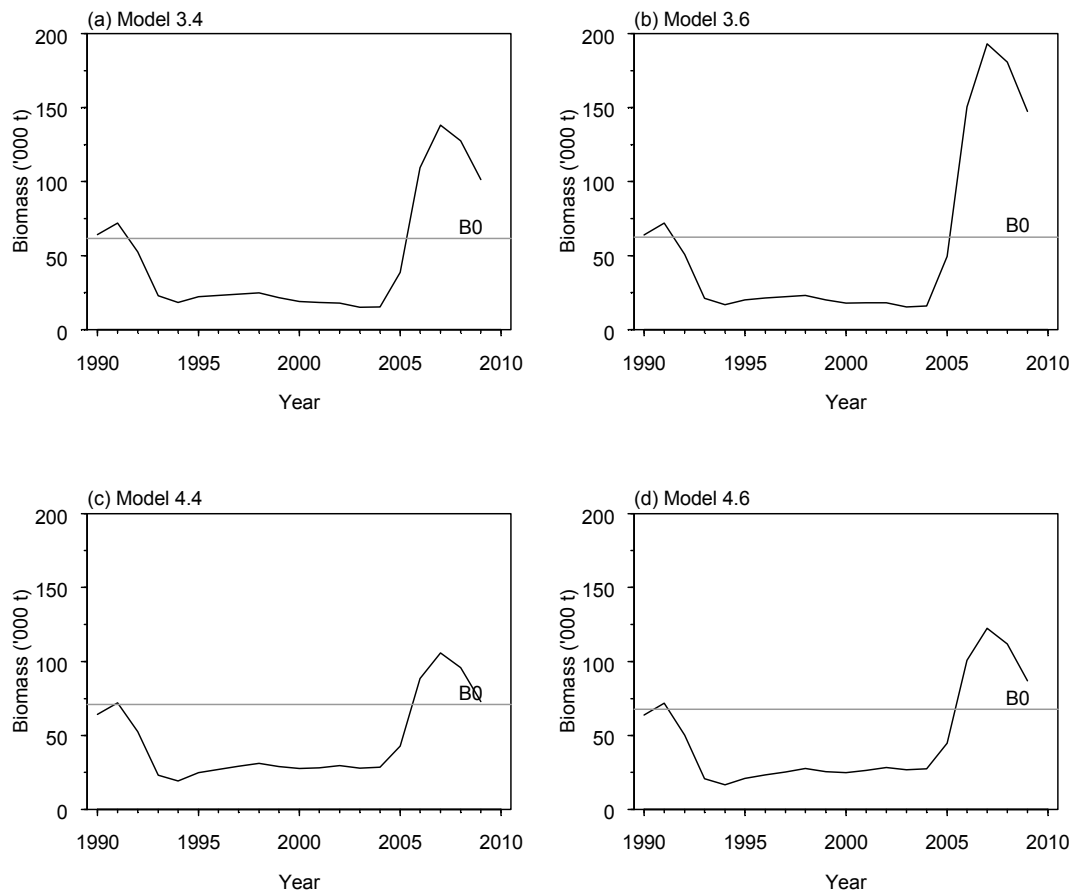
Initial MPD fits were evaluated for fits to the catch-at-age data and the adult acoustic indices for the four final models (models 3.4, 3.6, 4.4, and 4.6). Estimates of  $B_0$  and  $B_{\text{initial}}$  were very similar for all four runs but the recent stock trajectory and estimates of  $B_{2009}$  were very different between runs (

Table 7, Figure 8). Models 3.4 and 3.6, which had tight priors, had much higher current biomass estimates than models 4.4 and 4.6.

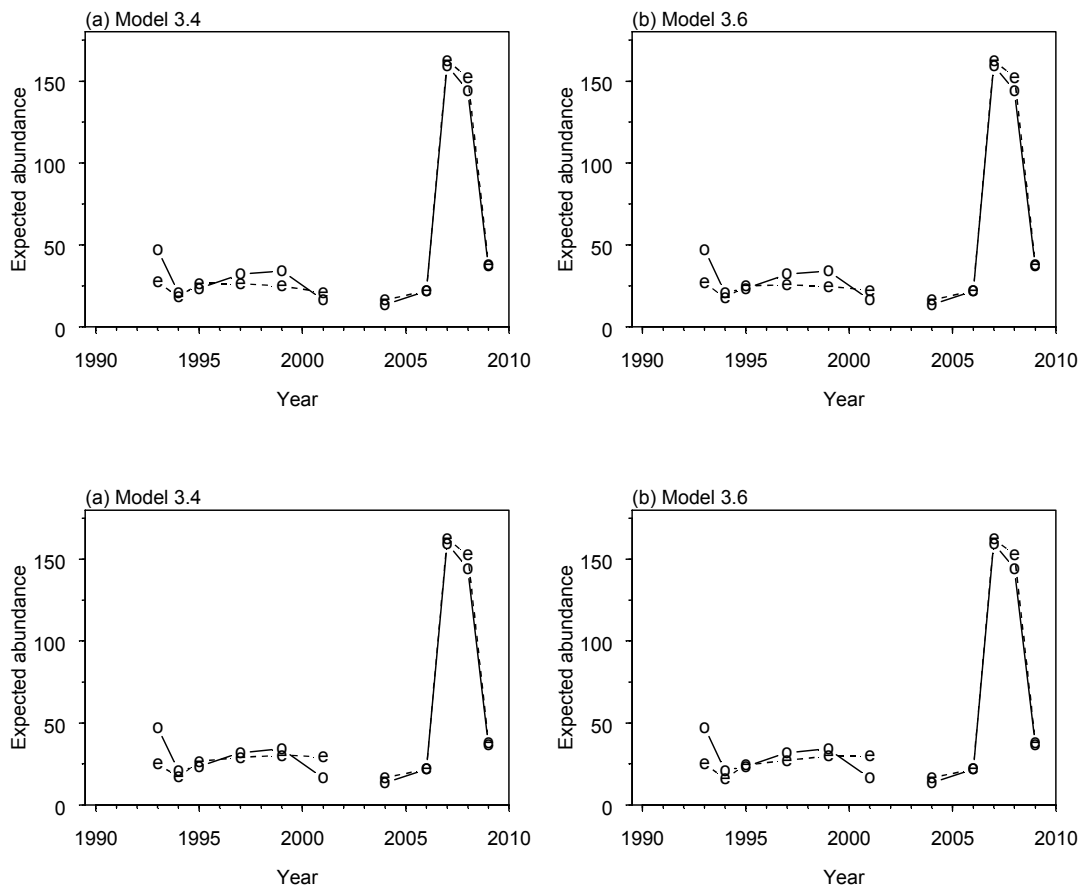
All four models were able to track the very large increases and decreases seen in the acoustic indices and had similar overall fits (Figure 9). All four models also fitted the trajectory of mean age reasonably well, although the two size-based models performed slightly better since about 2000 (Figure 10). The key difference between the four models is the strength of the 2002 year class, which ranges from less than 20 in model 4.4 to over 40 in model 3.6 (Figure 11).

**Table 7: MPD estimates of equilibrium biomass ( $B_0$ ) initial biomass ( $B_{initial}$ ), current biomass ( $B_{2009}$ ) and current biomass as a percent of  $B_0$  for model runs 3.4, 3.6, 4.4, and 4.6.**

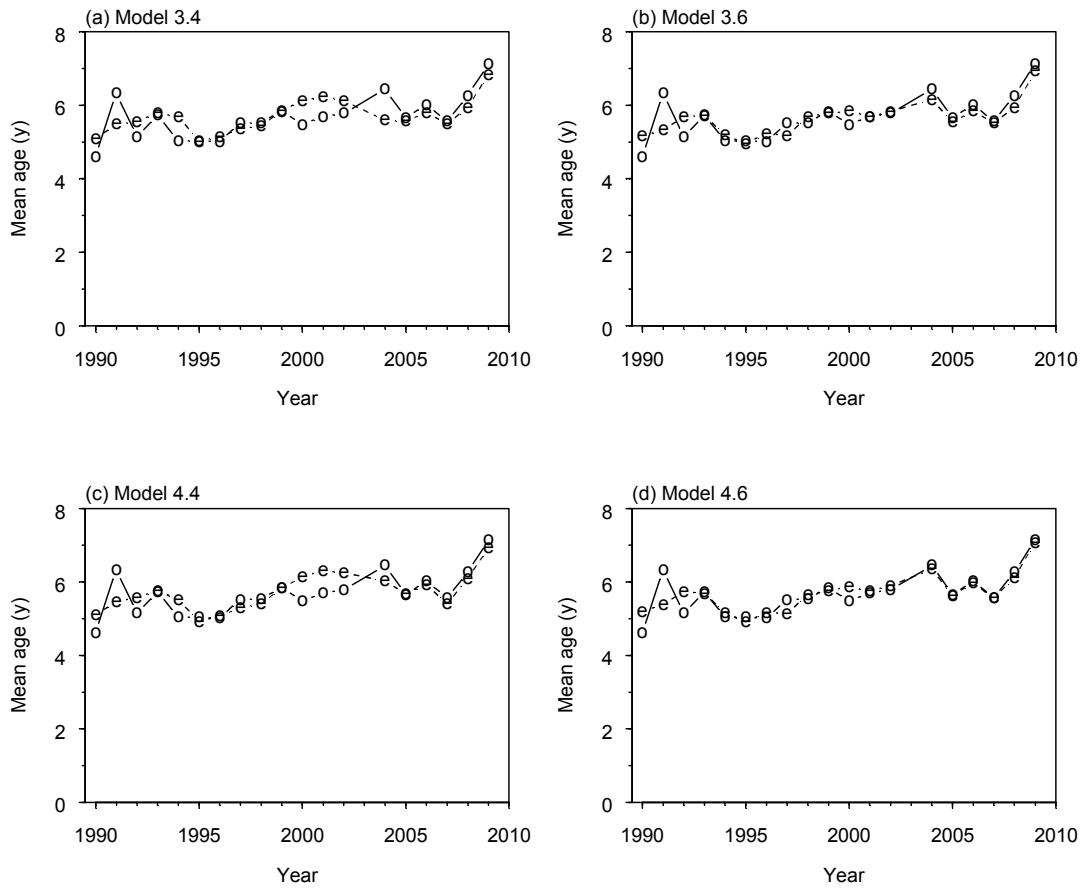
Model	$B_0$	$B_{initial}$	$B_{2009}$	$B_{2009}/B_0$ (%)
Model 3.4	61 704	58 181	101 203	164.0
Model 3.6	62 391	58 239	147 449	236.3
Model 4.4	70 894	58 277	73 006	103.0
Model 4.6	67 604	58 166	86 929	128.6



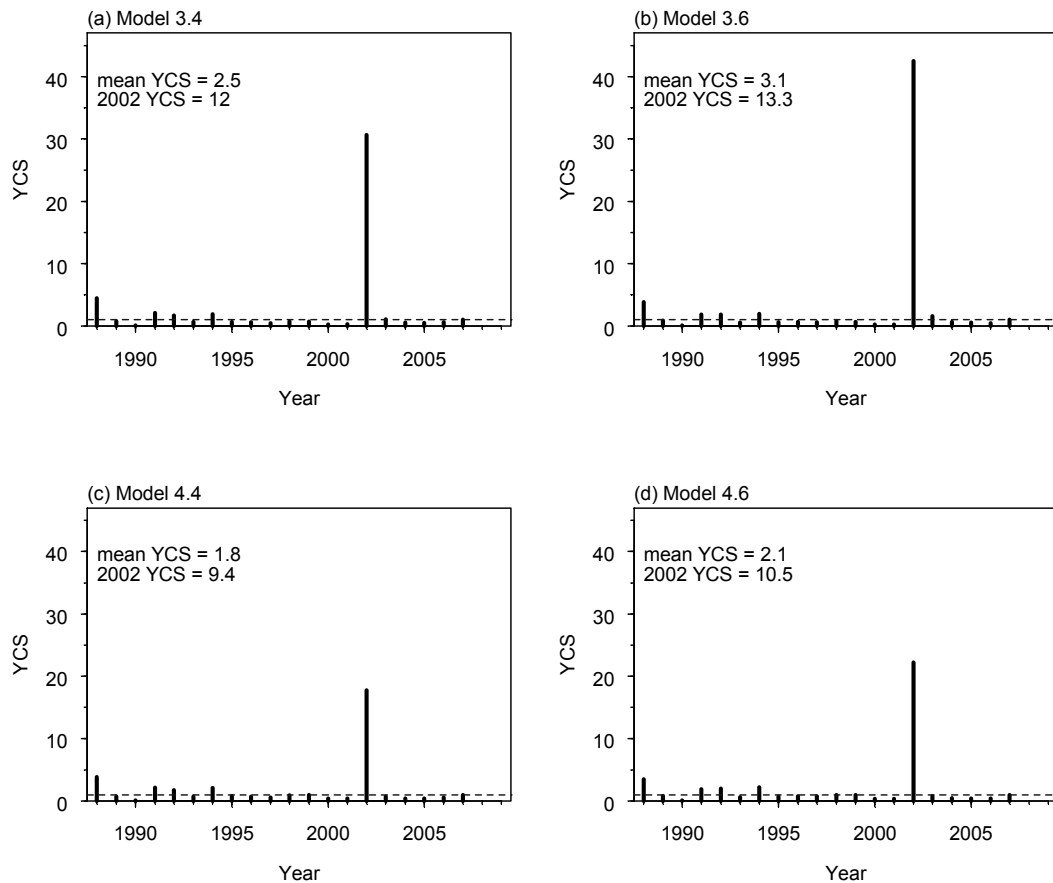
**Figure 8: MPD estimates of mid-season spawning stock biomass for the tight prior models with (a) age based selectivities (model 3.4), and (b) size-based selectivities (model 3.6) and the diffuse prior models with (c) age based selectivities (model 4.4), and (d) size-based selectivities (model 4.6).**



**Figure 9: Observed (o) and expected (e) fits to the wide area and local area aggregation biomass indices for the tight prior models with (a) age based selectivities (model 3.4), and (b) size-based selectivities (model 3.6) and the diffuse prior models with (c) age based selectivities (model 4.4), and (d) size-based selectivities (model 4.6).**



**Figure 10: Observed (o) and expected (e) mean ages for the tight prior models with (a) age based selectivities (model 3.4), and (b) size-based selectivities (model 3.6) and the diffuse prior models with (c) age based selectivities (model 4.4), and (d) size-based selectivities (model 4.6).**



**Figure 11:** Estimated relative year class strengths for the tight prior models with (a) age based selectivities (model 3.4), and (b) size-based selectivities (model 3.6) the diffuse prior models with (c) age based selectivities (model 4.4), and (d) size-based selectivities (model 4.6). Plots also show the mean of the year class strengths from the period 1988–2006 including the 2002 year class, and the equivalent 2002 year class multiplier assuming a mean of one for the period 1988–2006.

### 3.3 MCMC results

#### 3.3.1 MCMC diagnostics

MCMC diagnostics for the four models are shown in Figures 12–19. Trace plots for the key parameters ( $B_0$  and  $B_{2009}$ ) were not ideal and showed some evidence of large scale correlation between iterations. The lag plots for the tight prior models (3.4 and 3.6) identified problems with some autocorrelation in parameters for up to 6000–7000 iterations (Figures 13 and 15). There was little evidence for similar autocorrelations in the diffuse prior models (4.4 and 4.6).

Plots of median jump size indicated that the shift parameters for the 2005–2007 selectivity shift for the 2007 year for the models 3.4 and 4.4 had poor chain performance. This was also indicated by chain convergence tests of Geweke (1992) and Heidelberger & Welch (1983) stationarity and half-width tests that tended to indicate some evidence for poor convergence of at least one of the shift parameters in all of the models.

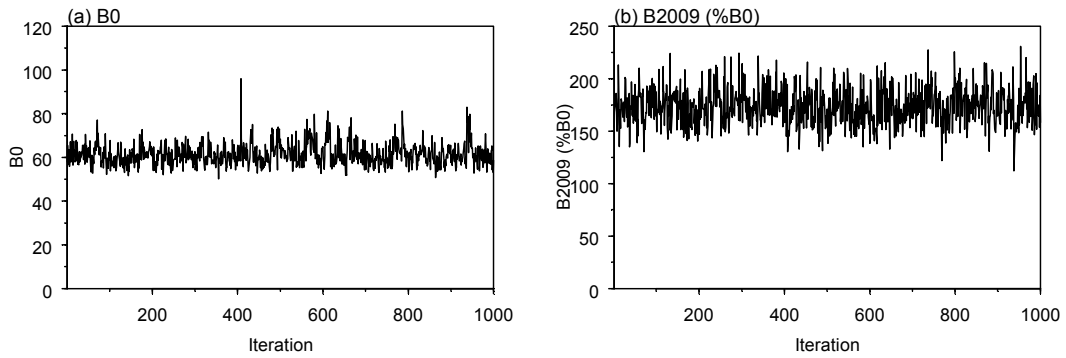


Figure 12: MCMC posterior trace plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 3.4.

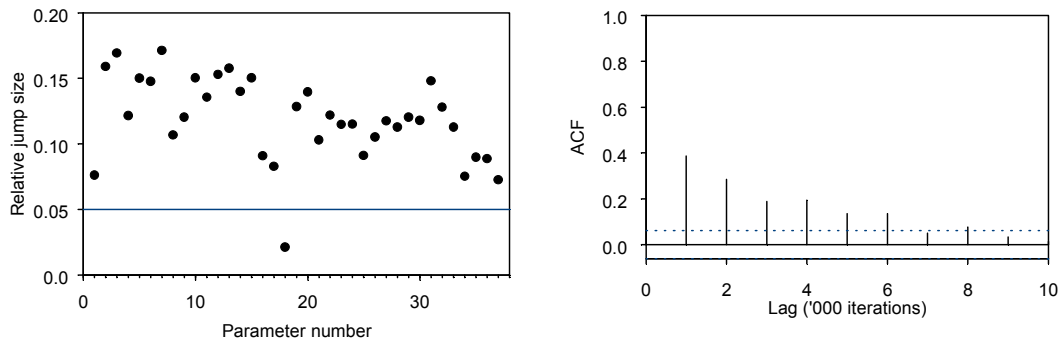


Figure 13: MCMC posterior diagnostic plots for model 3.4, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for  $B_0$ .

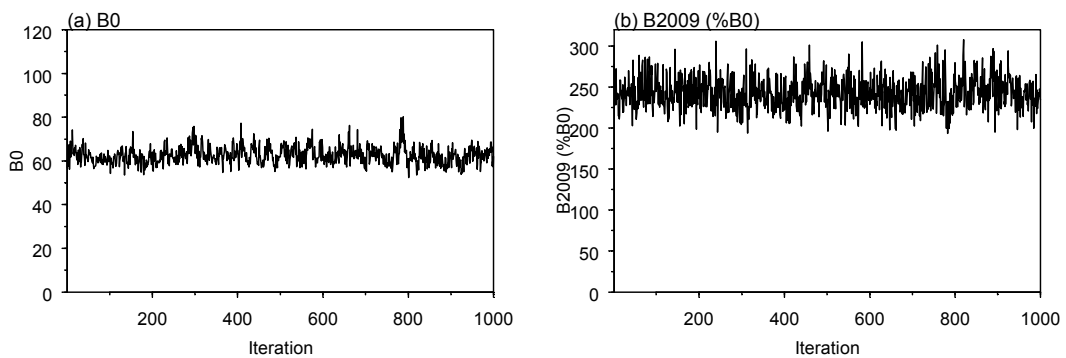


Figure 14: MCMC posterior trace plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 3.6.

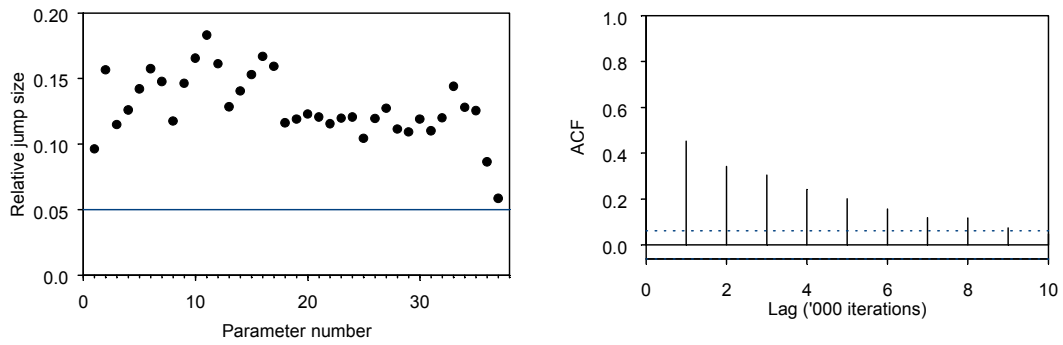


Figure 15: MCMC posterior diagnostic plots for model 3.6, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for  $B_0$ .

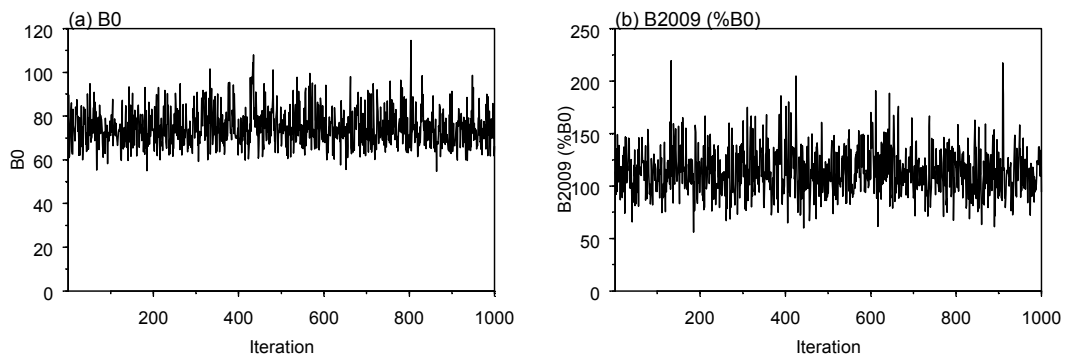


Figure 16: MCMC posterior trace plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 4.4.

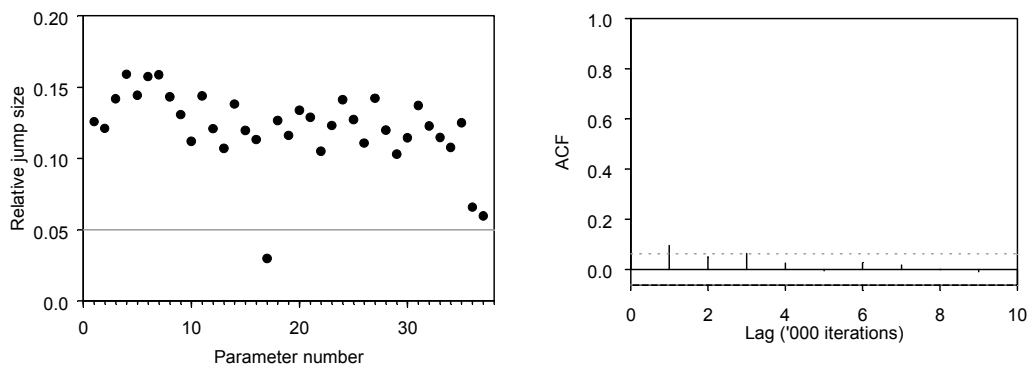
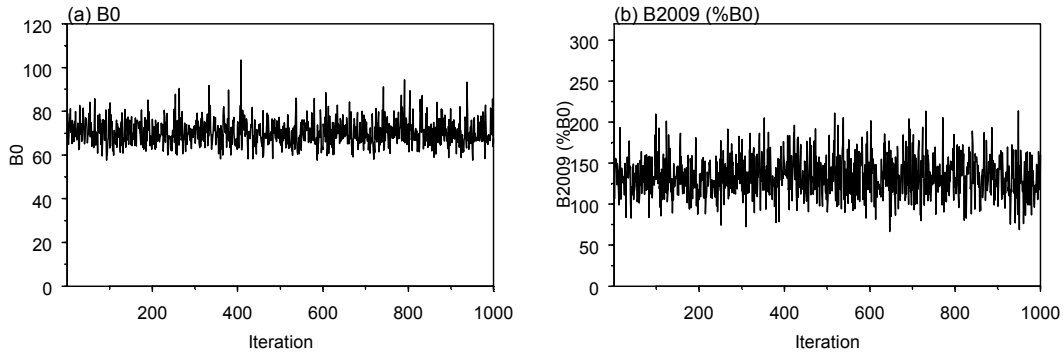
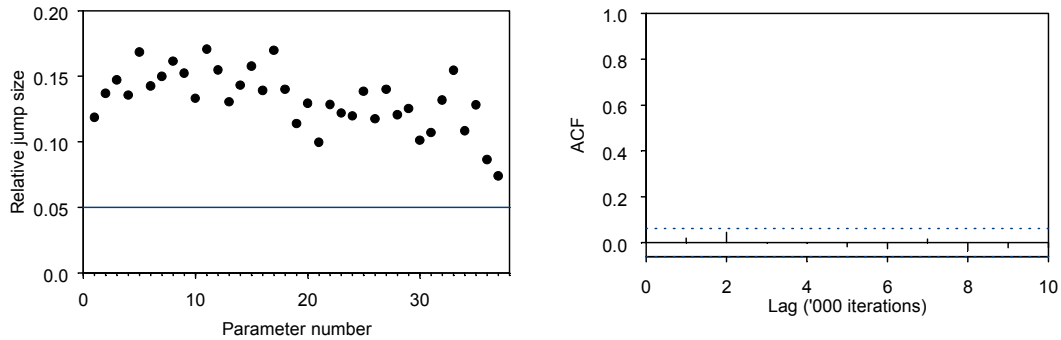


Figure 17: MCMC posterior diagnostic plots for model 4.4, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for  $B_0$ .



**Figure 18: MCMC posterior trace plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 4.6.**



**Figure 19: MCMC posterior diagnostic plots for model 4.6, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for  $B_0$ .**

### 3.3.2 MCMC estimates

MCMC posterior plots for  $B_0$  and current biomass ( $\%B_{2009}/B_0$ ) are shown for the four models in Figures 20–23 and the results summarised in Table 8. The MCMC results were similar to those from the MPD for all models. Median estimates of  $B_0$  were similar across models and ranged from 60 000 to 73 000 t. Estimates of  $B_0$  from the diffuse prior models (4.4 and 4.6) were slightly higher than the estimates from the tight prior models (3.4 and 3.6).

Median estimates of  $B_{2009}$  were much more variable, ranging from 82 000 to 150 000 t. The highest estimates of  $B_{2009}$  came from the tight prior model with the size based fishing selectivity (model 3.6). The other three models were more similar with estimates of  $B_{2009}$  ranging from 82 000 to 105 000 t.



Estimates of the catchability coefficients ( $q$ ) for the aggregation biomass indices for the model runs are summarised in Tables 9 and 10. Estimates of the adult (4+) catchability coefficient  $q$  for the wide area surveys were reasonably similar for the four models ranging from 0.98–1.23. However, in order to fit the various acoustic local area aggregation surveys the estimates of  $q$  from the individual aggregation surveys ranged from 0.33 to 2.05 across the various model runs and surveys fitted. The catchability coefficients need to be interpreted with some caution because they are fitted to the model biomass estimates via the selectivity ogive and the selectivity ogive was right shifted (by about a year) for the two size-base selectivity models 3.6 and 4.6. (This means that the  $q$ s for model 3.4 should be best compared with model 4.4 and for model 3.6 should be compared with model 4.6.) Notwithstanding this, we believe that the estimates of the adult acoustic  $q$  for southern blue whiting should be reasonably close to 1, and that the median estimates from model runs 3.6, 4.4 and 4.6 for the 2007 and 2008 surveys might be less plausible. The estimates of adult acoustic  $q$  for model 3.4 are the most plausible across the entire time series of wide area and aggregation surveys.

**Table 8: Estimates of equilibrium ( $B_0$ ), initial, and current biomass for the model runs**

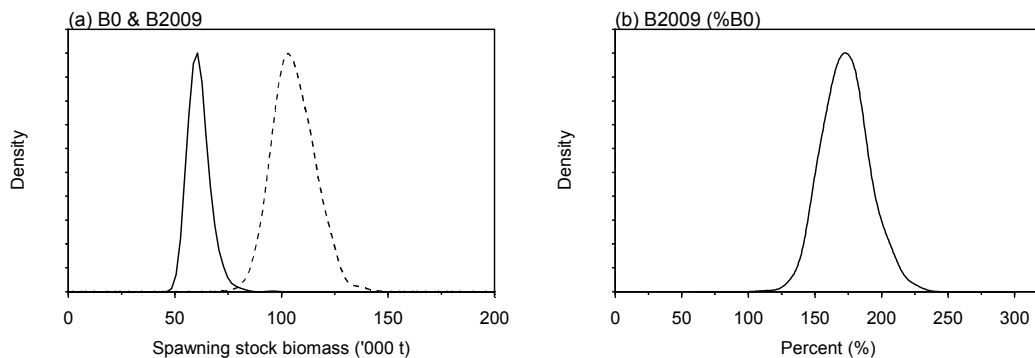
Model	$B_0$	$B_{2009}$	$B_{2009} (\%B_0)$
Model 3.4	60 710 (53 270–72 930)	105 020 (88 470–125 170)	173 (143–210)
Model 3.6	62 100 (55 720–70 550)	150 420 (132 990–171 920)	242 (206–283)
Model 4.4	73 180 (61 030–94 010)	82 080 (51 190–130 270)	111 (74–162)
Model 4.6	69 580 (60 150–82 830)	92 290 (57 510–138 330)	132 (88–186)

**Table 9: Estimates of the catchability coefficients ( $q$ ) for the wide area biomass indices for the model runs**

Model	Age 2	Age 3	Age 4
3.4	1.58 (1.41–1.79)	2.06 (1.78–2.42)	1.13 (0.97–1.31)
3.6	1.59 (1.47–1.73)	2.06 (1.85–2.32)	1.23 (1.13–1.32)
4.4	1.13 (0.85–1.42)	1.51 (1.14–1.92)	0.98 (0.76–1.18)
4.6	1.21 (1.00–1.44)	1.59 (1.29–1.90)	1.11 (0.98–1.24)

**Table 10: Estimates of the catchability coefficients ( $q$ ) for the aggregation biomass indices for the model runs**

Model	2004	2006	2007	2008	2009
3.4	1.07 (0.88–1.27)	0.19 (0.15–0.24)	1.15 (0.98–1.34)	1.16 (0.99–1.35)	0.36 (0.30–0.43)
3.6	1.11 (0.97–1.26)	0.33 (0.29–0.37)	1.41 (1.26–1.55)	1.14 (1.02–1.26)	0.33 (0.29–0.37)
4.4	0.48 (0.30–0.78)	0.22 (0.14–0.33)	1.41 (0.94–2.07)	1.44 (0.95–2.16)	0.46 (0.29–0.74)
4.6	0.55 (0.38–0.79)	0.41 (0.29–0.58)	2.05 (1.44–2.80)	1.74 (1.20–2.64)	0.53 (0.35–0.87)



**Figure 20: MCMC posterior plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 3.4.**

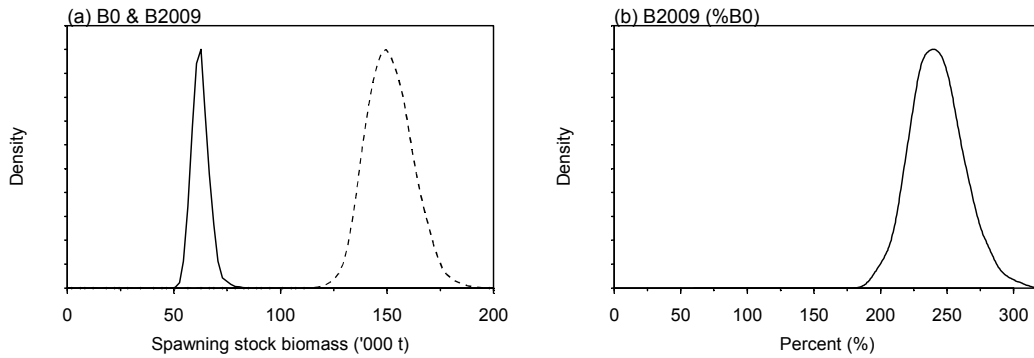


Figure 21: MCMC posterior plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 3.6.

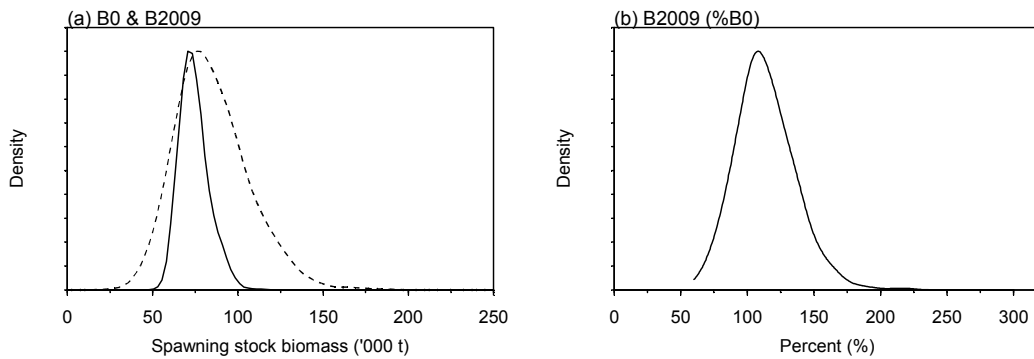


Figure 22: MCMC posterior plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 4.4.

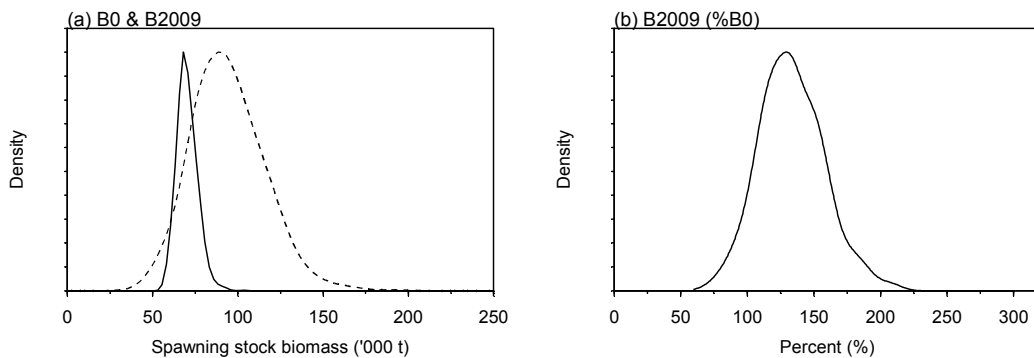


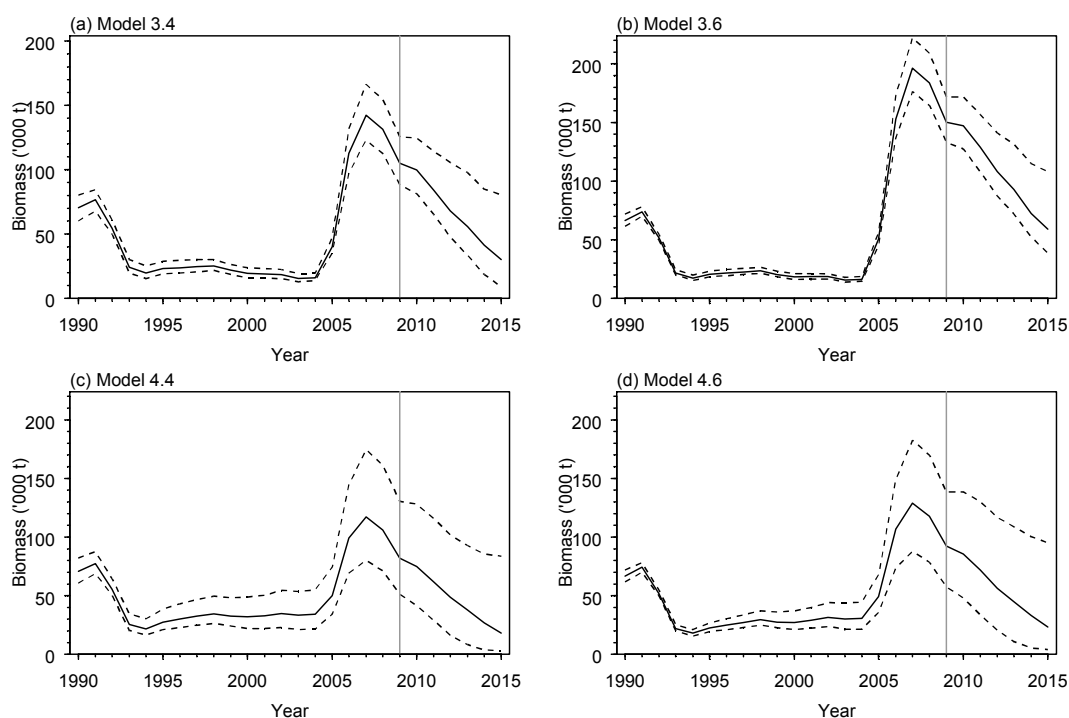
Figure 23: MCMC posterior plots for (a)  $B_0$  and (b) current biomass ( $\%B_{2009}/B_0$ ) for model 4.6.

### 3.4 Projections

Projections were made assuming fixed catch levels of 15 000 t per year using the MCMC samples for each of the four models. Recruitments were drawn randomly from the distribution of year class strengths estimated by the model, excluding the 2002 year class as discussed above. The probability that the mid-season biomass will be less than the threshold level (20%  $B_0$ ) at catch levels of 15 000 t is less than 10% for all models and years (Table 11). Under average recruitment conditions the models predicted that biomass is expected to decrease after 2009 under a catch of 15 000 t, but, in all scenarios, is still expected to be above 50%  $B_0$  by 2013 (Figure 24).

**Table 11: Probability that the projected mid-season vulnerable biomass for 2010–2013 will be less than 20%  $B_0$ , and the median projected biomass as a % $B_0$ , for the Bounty Platform stock, at a projected catch of 15 000 t for models 3.4, 4.6, 4.4, and 4.6.**

Catch	Model	Pr (SSB < 0.2 $B_0$ )				Median SSB (% $B_0$ )			
		2010	2011	2012	2013	2010	2011	2012	2013
15 000 t	Model 3.4	0.00	0.00	0.00	0.00	163.9	137.9	110.9	90.3
	Model 3.6	0.00	0.00	0.00	0.00	236.7	206.4	172.8	148.4
	Model 4.4	0.00	0.00	0.02	0.09	102.4	84.5	65.3	51.1
	Model 4.6	0.00	0.00	0.01	0.04	121.9	102.3	80.5	63.8



**Figure 24: MCMC posterior plots for the median (solid line) and 95% credible intervals (dashed lines) for  $B_0$  for (a) model 3.4, (b) model 3.6, (c) model 4.4, and (d) model 4.6. The vertical line represents the beginning of the projection period (2010–2015).**

#### 4. DISCUSSION

Previous modelling work suggested that the spawning stock biomass from the Bounty Platform had become depleted during the early 2000s (e.g., Hanchet 2000, 2002) and the TACC was subsequently reduced to 3500 t in 2003–04. An assessment of the stock in 2005 indicated that the stock was still depleted and that there was a higher than 10% probability that the biomass was below 20%  $B_0$  (Hanchet 2005). At that time, the Plenary document noted that the stock was unlikely to rebuild until a strong year class entered the fishery (Ministry of Fisheries Science Group 2006).

Because of the low TACC, it became uneconomic to continue the time series of wide area acoustic indices. However, in 2004 the industry investigated the potential for industry vessels to collect acoustic data from local aggregations whilst fishing for southern blue whiting on the Bounty Platform (O'Driscoll 2011). Surveys were carried out in each of the years 2004–2009, but the surveys had mixed levels of success. There was also some concern that the surveys in 2006 and 2009 did not sample an entire aggregation because on several transects the fish

marks extended beyond the area being surveyed (O'Driscoll 2011). Recent stock assessments which have attempted to fit the series of aggregation surveys were unable to reconcile the very sharp increase in adult biomass seen through the series with the observed proportions-at-age in the commercial fishery (Hanchet & Dunn 2009a, 2009b). In this assessment we were able to reconcile these conflicting data sources only by freeing up assumptions of constant catchability between the aggregation data surveys, by treating the proportion-at-age data as three separate fisheries, and by having priors linking the acoustic catchability between the wide-area and local area aggregation acoustic surveys. One of the key issues with the assessment has been how to treat local area aggregation surveys when the overall proportion of the adult biomass sampled by each survey is unknown. We have treated the individual surveys as having separate catchabilities, but emphasise that in doing so we degrade the information on biomass that these survey may provide.

There is little doubt that the 2002 year class is one of the strongest year classes seen in the southern blue whiting fishery. However, the actual size of it, and therefore the size of the current biomass and associated yields is extremely uncertain. The four model runs provided a range of possible estimates of  $B_{2009}$  ranging from 82 000 to 150 000 t. Although the MPD fits for all the runs looked reasonable, the MCMC trace diagnostics and autocorrelation lag plots suggested problems with models 3.4 and 3.6 which gave the highest biomass estimates. On the other hand, estimates of the adult acoustic  $q$  were higher than might be considered plausible for several surveys for model runs 3.6, 4.4, and 4.6. Therefore, there is no clear indication of which model may be more likely.

Since this modelling work was completed, an additional aggregation survey was carried out on the Bounty Platform in August 2010 (R. O'Driscoll, NIWA, pers. comm.). Two snapshots were completed during the survey which appeared to fully cover the spawning aggregation — the snapshots were completed in the main area being fished at the time and no fish marks were visible at the end of each transect or in the first and last transects at either side of the survey area. However, the estimate of adult biomass from the two snapshots was similar to that recorded for 2009 and was between 25 000 and 30 000 t. Various reasons for the much lower observed biomass estimates from surveys in 2009 and 2010 compared with 2007 and 2008 were explored, including changes in survey methodology, equipment (including calibration), and changes in timing and extent of survey coverage. No reason for these low estimates was found and the low estimates of biomass were likely to be real and reflected real changes in southern blue whiting abundance at the Bounty Platform. In general, without wide-area surveys to provide 'ground truthing' for such aggregation surveys results, it is impossible to determine whether such reductions in observed biomass are likely to be due to a poor survey or a real reduction in stock size.

Given the low biomass estimates in 2009 and 2010, we therefore conclude that the estimates of current biomass calculated from the model are likely to be biased high. Further, we note that some of the model assumptions (e.g., the assumption of a constant rate of natural mortality or the priors on the acoustic surveys for 2007–2009) will need to be investigated to resolve the inconsistency.

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