Ministry for Primary Industries
Manatū Ahu Matua

Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform up to, and including, the 2011 season

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Growing and Protecting New Zealand

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report documents the further development of a stock assessment of the Bounty Platform for the period 1990–2011 using catch history, proportion-at-age, and acoustic survey data up to and including the 2011 season. The primary data sources on abundance were the R.V. *Tangaroa* wide area acoustic surveys carried out from 1993 to 2001, the industry vessel aggregation acoustic surveys carried out from 2004 to 2011, and the age data from 1990 to 2011. Estimates of adult biomass from the surveys showed a sevenfold increase from 2006 to 2007 followed by a fivefold 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. However, the large decline in biomass from 2008 to 2009 could not be explained by changes in population abundance due to fishing or natural mortality.

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. In this assessment we were only able to reconcile the conflicting data sources by freeing up assumptions of constant catchability between the aggregation surveys, by fixing the wide area age 4+ acoustic catchability coefficient at 1.0, and by having priors linking the acoustic catchability between the wide-area and aggregation surveys. The four model runs provided estimates of B_{2011} ranging from 31 000–81 000 t. Although the MPD fits and MCMC diagnostics for all runs looked reasonable, two models were unable to fit the most recent age data, and in two models the values of the adult acoustic q were higher than might be considered plausible.

Because of the problems with the stock assessment, essentially arising from difficulties in fitting the aggregation survey data, the stock assessment results were not used for providing management advice. Instead, the catch limit for the 2012–13 season was based on a proxy yield calculated by multiplying the 2011 acoustic survey estimate by the U_{CAY} exploitation rate, which equalled 6500 t.

The key uncertainty with the current stock assessment is the treatment of the aggregation surveys because the overall proportion of the adult biomass sampled by each survey is unknown. We recommend that a wide area survey be carried out so that a snapshot of total adult biomass can be obtained.

1. INTRODUCTION

Southern blue whiting (*Micromesistius australis*) 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 35–50 cm fork length (FL), although occasionally smaller size classes of males (29–32 cm FL) have been observed in the catch (Cole et al. 2013).

Commercial fishing has been concentrated on the Campbell Island Rise and, to a lesser extent, the Bounty Platform. The Pukaki Rise and Auckland Islands are smaller fisheries, with much lower annual catches compared with the Campbell Island Rise and Bounty Platform fisheries (Cole et al. 2013).

Wide area acoustic surveys using R.V. *Tangaroa* and assessments of the Bounty Platform stock were carried out in alternate years up until 2002 (e.g., Hanchet et al. 2002, Hanchet et al. 2003). At that time, acoustic indices and subsequent assessments of the Bounty Platform 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 (Cole et al. 2013). A new time series of local area aggregation surveys was initiated in 2004, and additional acoustic surveys were completed in 2006, 2007, 2008, 2009, 2010, and 2011 using industry vessels (Cole et al. 2013).

A stock assessment for southern blue whiting on the Bounty Platform using the acoustically-derived biomass 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 very large increase in biomass resulting from 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 (Dunn & Hanchet 2011, Hanchet & Dunn 2009a, 2009b). This was primarily due to a conflict 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. Since then, the observed biomass estimates for 2009, 2010, and 2011 from local area aggregation surveys have found a much lower biomass than was observed in 2007 and 2008, and the very large (fivefold) reduction in the observed biomass remained unexplained. As a result, yield estimates for the Bounty Platform for recent years have been based on an estimate of proxy yield calculated from an absolute biomass estimate from the recent survey multiplied by a U_{CAY} exploitation rate (Ministry of Fisheries 2011).

This report documents the attempts to develop a stock assessment of the Bounty Platform using the data up to and including the 2011 season using the early wide area (R.V. *Tangaroa*) and recent local area aggregation acoustic survey indices and commercial catch proportions-at-age data. We consider the assumptions required to fit to recent local area biomass estimates within a stock assessment model, and the implications of these assumptions on estimates of stock status. Because of the problems with the stock assessment, essentially arising from difficulties in fitting the aggregation survey data, we also update the estimate of proxy yield calculated in recent years.

This report is in fulfilment of the Ministry of Fisheries Project DEE201002SBWA (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).
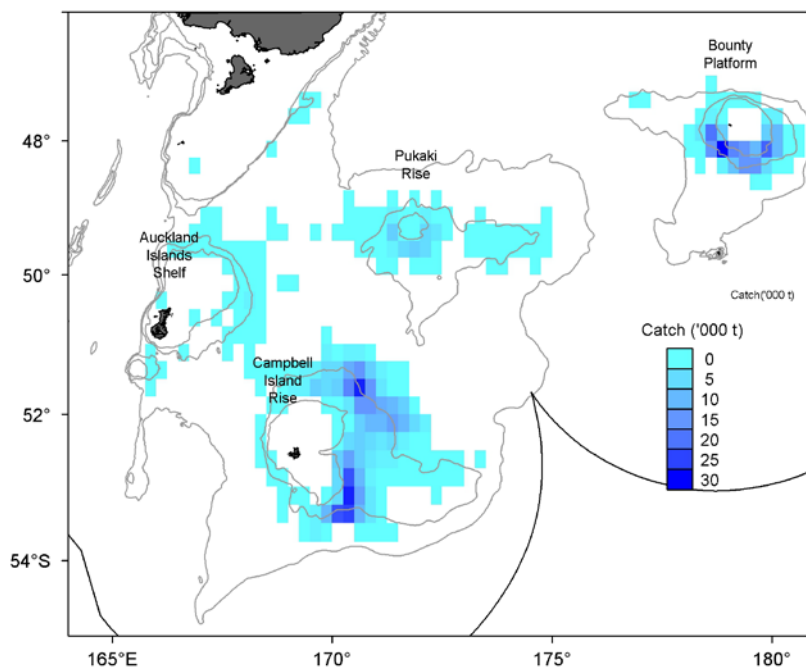
Figure 1: Relative total density of the commercial catch of southern blue whiting by 0.25º × 0.25º cells from TCEPR data 1990–2011.

2. METHODS

Preliminary model runs were not able to satisfactorily fit all of the points in the time series of aggregation acoustic survey estimates. Hence, the development of the assessment models focused on investigating the outcomes of fitting either (i) the early part of the aggregation survey time series, (ii) the later part of the time series, or (iii) model assumptions that may allow both parts to be equally fitted. 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. 2012). 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 2011. 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 take 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 below) and their mean size at age (Cole et al. 2013).

Southern blue whiting exhibit large inter-annual differences in growth rate, presumably caused by local environmental factors, 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 length at age of fish in the model, but rather an empirical length-at-age matrix for each year (Appendix 1). The annual length-at-age matrix was derived by qualitatively reviewing the empirically estimated mean lengths-at-age from the commercial

catch-at-length and -age data (Cole et al. 2013). Missing estimated mean lengths in the matrix were inferred from the relative size of their cohort and the mean growth of similar ages in other years; and cohorts with unusually small or large increments were similarly adjusted.

The mean length-at-ages in the future years were required for projections and calculated as follows. The mean length in 2012 was calculated by adding the observed mean percentage growth increment from 1990–2011 to each age class in 2011 to determine their expected lengths in 2012, with the mean length of age 2 fish in 2012 assumed to be equal to the mean of the annual mean lengths of age 2 fish from 1990–2011. By iteratively applying the above algorithm, the mean lengths for males and females for the years 2013 to 2016 were also determined (Appendix 1).

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 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. Note that the length-weight relationship was assumed to be constant across years.

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 0.7. In some previous models of southern blue whiting on the Bounty Platform, 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 that are mature (see Figure 2), and estimate a logistic shaped fishing selectivity for males and females separately. Note that the fixed maturity ogive was based on the mean age at maturity for the Campbell Island stock and was assumed to be constant across years.

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 (described as a Cinitial starting state in Bull et al. 2012). The second and third started at the beginning of the known fishery in 1971 and assumed that the population in 1971 was at the mean equilibrium unexploited level (labelled B_0), or that the population in 1971 was not at equilibrium, but with 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 is 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 years 1988–2008 equal one with the constraint that the mean of the relative year class strengths for the years 1988–2001 and 2003–2008 combined equal one. This modification removed most of the confounding between key parameters, and resulted in much more numerically stable models.

Note that the consequence of this is that the estimated equilibrium unexploited spawning biomass (B_0) is no longer defined as the spawning biomass that there would have been if the

mean relative year class strength was equal to one over the period of the fishery (see Bull et al. 2012 for rationale). Instead, in this model it is the spawning biomass that there would have been if the mean relative year class strength was equal to one, excluding the 2002 year class, and with no fishing. Further, 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 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.

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 two) assumed to be 0.5 of all recruits.

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
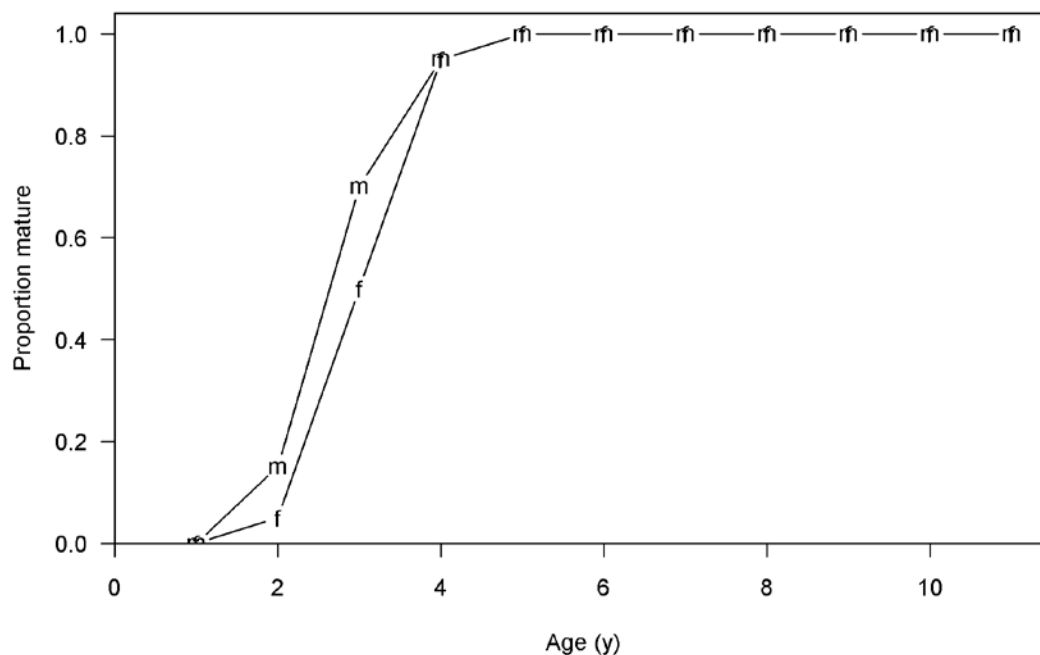
Figure 2: Assumed proportions mature for males (m) and females (f) for the Bounty Platform.

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 the years 1993–1996, 1997, 1999, and 2001 (Cole et al. 2013).

We assume that the wide area survey acoustic biomass estimates were of southern blue whiting aged 2, 3, and 4+ (Table 2), and that these were relative estimates of mid-season

biomass (i.e., after half the catch has been removed), with a CV equal to sampling CV estimated from the survey. The wide area acoustic biomass observations were fitted using a lognormal likelihood, i.e.,

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

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

where O_i are the observed biomass estimates at time i with CVs c_i, E_i are the model expected biomasses at time i and q is the catchability coefficient for the biomass series and was set to be constant for the entire series.

Table 2: 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	CV	Biomass	CV	Biomass	CV	Biomass	CV
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 from 2004 to 2011 (O'Driscoll 2011a, 2011b, 2012). Industry vessels opportunistically collected acoustic data from the Bounty Platform fishing grounds using a stratified random survey design over an ad-hoc area that encompassed at least part of an aggregation of southern blue whiting (O'Driscoll & Hanchet 2004, O'Driscoll et al. 2006, O'Driscoll et al. 2007, O'Driscoll & Dunford 2008, O'Driscoll et al. 2009, O'Driscoll 2011b, O'Driscoll 2012). The results are given in Table 3. The aggregation surveys had mixed levels of success. 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 and inadequate survey design. 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.

For the stock assessment modelling, 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 CV equal to the sampling CV estimated from the survey. However, as the proportions of the population that was covered by the aggregation surveys were likely to have been different in each year, the series was assumed to be a time series with non-constant catchability. We assume that the catchability coefficient (q) for the biomass estimate from each year was a separate parameter, but link each of the biomass estimates from the surveys using a prior on the relative value of the catchability to the wide area survey catchability estimate. Hence, we allow the biomass estimates to provide some information to the model by assuming 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. 2012 for detail). The prior distribution on the ratio of catchabilities for the local area aggregation surveys and the wide area surveys was assumed to be lognormally distributed and parameterised by a mean and CV (see also Section 2.3.1).

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

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

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

where O_i are the observed biomass estimates at time i with CVs 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.

Table 3: The local area acoustic biomass estimates for the Bounty Platform with the revised target strength and sound absorption coefficient, 2004–2011.

Year	Biomass	CV	Source
2004	13 473	0.69	(O'Driscoll & Hanchet 2004)
2006	21 765	0.12	(O'Driscoll et al. 2006)
2007	159 589	0.19	(O'Driscoll et al. 2007)
2008	144 187	0.34	(O'Driscoll & Dunford 2008)
2009	28 242	0.24	(O'Driscoll et al. 2009)
2010	27 782	0.36	(O'Driscoll 2011b)
2011	35 597	0.28	(O'Driscoll 2012)

2.2.3 Proportions-at-age in the catch

Catch-at-age observations by sex were available from the commercial fishery for 1990 to 2011 from observer data (Figure 3). Commercial catch-at-age data were fitted to the model as proportions-at-age by sex, where associated CVs 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.,

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

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.
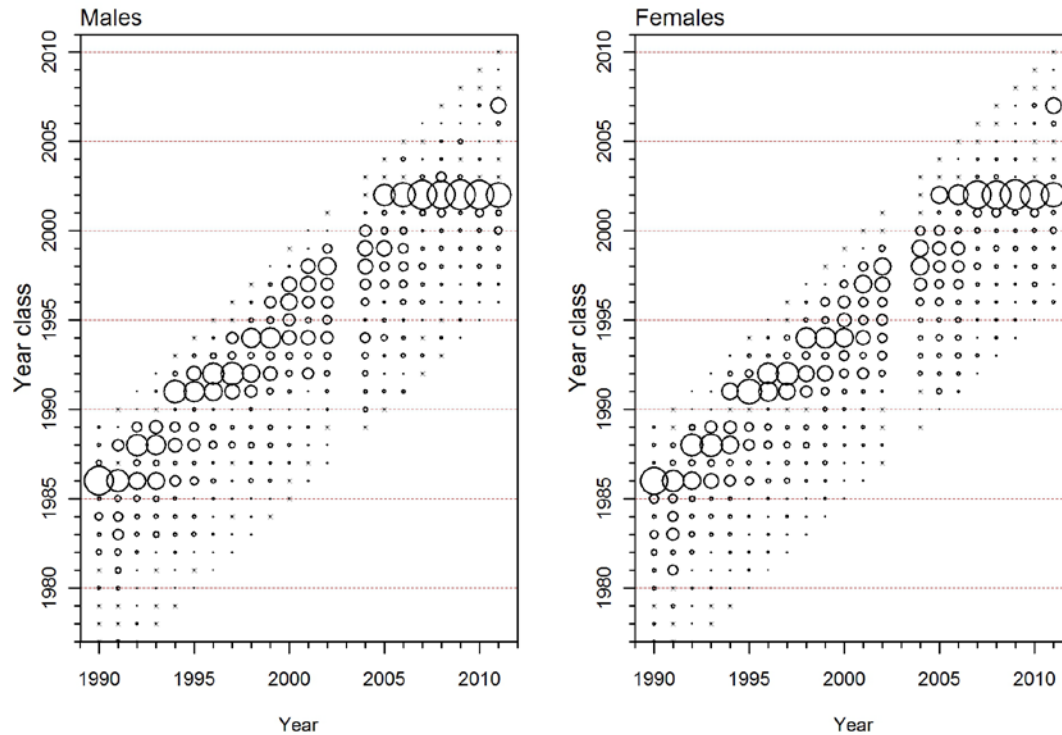
Figure 3: Commercial catch proportions at age for the Bounty Platform stock by sex and year class, 1990–2011 for ages 2–11+. Symbol area proportional to the proportions-at-age within the sampling event.

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 **p**, the vector of the free parameters, L the likelihood function, and O_i the ith observation was,

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

Where θ is the joint prior (and penalty) density of the parameters **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 π, scaled by an unknown constant. The algorithm generates a 'chain' or sequence of values. Typically the beginning of the chain is discarded and every nth 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 proposed distribution J, which should be symmetric i.e., $J(\text{-}s)=J(s)$, (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. 2012 for more detail), and used as the starting point for the chain.

MCMCs were estimated using a burn-in length of 1×10^6 iterations, with every $10\,000^{\text{th}}$ sample taken from the next 1×10^7 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. Following previous assessments (e.g., Dunn & Hanchet 2011), the prior assumed for the relative year class strengths was lognormal, with mean 1.0 and CV 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 CV was modified to be less constraining and set to 10 (Dunn & Hanchet 2011).

In preliminary model runs we tried estimating the age 4+ wide area acoustic survey catchability coefficient using a log-normal prior with mean 1.0 and CV 0.2. However, these model runs were unstable and so the decision was made to fix it at a particular value for all model runs. The prior previously used for the age 4+ 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. This approach suggested a mean of 1.4 and CV 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 in 2010 (see Dunn & Hanchet 2011) to have mean 1.0 with CV 0.2, and retained the same bounds. For the current assessment we therefore fixed the age 4+ wide area acoustic survey catchability coefficient at 1.0 for all model runs. This had the added advantage that the catchability coefficients were directly comparable across all four runs (see below).

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 and their CVs was based on the four interpretations of the changes in observed biomass between 2007–2008 and 2009–2011. The 2006 survey is known to have missed a substantial part of the population, and was assigned a q ratio prior of 0.5 and a CV of 0.5 in all scenarios. The remaining surveys were all assigned a mean q ratio prior of 1.0 but were assigned a CV of either 0.05 or 0.5 to up-weight or down-weight their effect in the model.

In the first scenario, we assumed that the biomass that was observed in the 2007–2008 and 2009–2011 aggregation surveys were simply the result of sampling variability, i.e., that the

true biomass trajectory was some average of the observed biomass indices. In this scenario, we equally weight the biomass indices by applying a high CV of 0.5 for each year (Table 5).

The second scenario assumed that the earlier aggregation surveys from 2004 to 2008 were imprecise. In this scenario, we up-weight the indices from 2009–2011 by assuming a tight q-ratio prior around 1.0 on their catchability coefficients compared with the wide area catchability coefficient.

The third scenario assumed that the aggregation surveys in 2009–2011 were imprecise. In this scenario, we up-weight the indices from 2007–2008 by assuming a tight q-ratio prior around 1.0 on their catchability coefficients compared with the wide area catchability coefficient.

In the fourth scenario, we assumed that all the aggregation surveys were imprecise, and also allowed for some additional mortality or migration event that removed some (potentially large) proportion of the biomass from the population. Here we assume equal weighting on all of the aggregation surveys estimates as in the first scenario, but add an additional mortality event between 2007 and 2011 to explain the decline.

The values of the prior assumed for the q ratio for each survey and for the scenarios are given in Table 5 below. In each case, the catchability constants were assumed to be nuisance parameters, i.e., the value of the q was chosen that minimised the objective function, calculated algebraically (see Bull et al. 2012 for more detail). A lognormal likelihood was used for the biomass indices, with observations O_i, CV c_i, and expected values qE_i:

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

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	Mean	CV	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 [1]	0.001	100
Wide area catchability 4+ q	1	Fixed	1.0	0.0	–	–
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
2010 local area catchability q	1	Uniform	–	–	0.1	2.8
2011 local area catchability q	1	Uniform	–	–	0.1	2.8

Values columns: Mean, CV. *Bounds* columns: Lower, Upper.

[1] All years except for 2002, where the CV = 10.

Table 5: The aggregation survey biomass time series estimates for the Bounty Platform (with the revised target strength and sound absorption coefficient) and the assumed *q* ratio prior for the modelled scenarios, 2004–2011.

Year	Biomass	CV	Equal weighting μ	Equal weighting CV	Up-weight 2009–2011 μ	Up-weight 2009–2011 CV	Up-weight 2007–2008 μ	Up-weight 2007–2008 CV
2004	13 473	0.69	1.00	0.50	1.00	0.50	1.00	0.50
2006	21 765	0.12	0.50	0.50	0.50	0.50	0.50	0.50
2007	159 589	0.19	1.00	0.50	1.00	0.50	1.00	0.05
2008	144 187	0.34	1.00	0.50	1.00	0.50	1.00	0.05
2009	28 242	0.24	1.00	0.50	1.00	0.05	1.00	0.50
2010	27 782	0.36	1.00	0.50	1.00	0.05	1.00	0.50
2011	35 597	0.28	1.00	0.50	1.00	0.05	1.00	0.50

2.3.2 Process error and data weighting

Lognormal errors, with known CVs, were assumed for the relative biomass and proportions-at-age data. The CVs 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 that the relationship between the observed proportions, E_i, and estimated CVs, 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', were made by adding additional process error, N_{PE}, to the sample size calculated in (a) above, where,

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

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},

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

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 CV for the biomass observations were made by fitting the process error within each MPD run, where the applied CV c'_i was determined from the process error c_{PE} and the observed CVs 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.

2.3.3 Projections

Projections were made assuming fixed catch levels of 15 000 t per year (the 2010–11 catch limit) 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 was calculated for each of the model runs.

3. RESULTS

3.1 Model runs

Four alternative scenarios were modelled. The first (labelled model 1.1) assumed equal weighted priors on the ratio of the catchabilities between all of the aggregation surveys. The second (model 1.2) up-weighted the 2009–2011 surveys by assuming a tighter q-ratio prior on their respective catchability coefficient estimates. The third (model 1.3) up-weighted the 2007–2008 aggregation surveys by assuming a tight q-ratio prior on their respective catchability coefficient estimates. The fourth assumed the same q-ratio priors as for model 1.1, but introduced an additional mortality process in 2009–2011 to explain the observed decline in biomass. In considering these 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. Preliminary model exploration suggested an additional process error for the commercial catch-at-age proportions of about $n=34$. We assumed that this was an adequate value for all of the modelled scenarios, and hence fixed additional process error for the commercial catch-at-age proportions at this value for all further model runs. The model runs discussed are summarised in Table 6.

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

Label   Description

1.1   Equal weighted q ratio priors
1.2   Up-weight the 2009–2011 q ratio priors
1.3   Up-weight the 2007–2008 q ratio priors
1.4   Equal weighted q ratio priors, with additional mortality 2009–2011

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 models (models 1.1, 1.2, 1.3, and 1.4). Estimates of B_{1990} were similar for all four runs but the recent stock trajectory and estimates of B_0 were very different between runs (Table 7, Figure 4). The model with an additional mortality event after 2008 (run 1.4) had a much higher estimate of B_0 than the other three models, but a much lower stock status. The model that up-weighted the 2007–2008 indices (run 1.3) had a much higher estimate of current biomass compared with the other three models. The other two models (runs 1.1. and 1.2) gave similar results to each other.

While all four models showed some evidence of an increase in abundance between 2007—2008 and the subsequent decline, they differed in their interpretation of the extent of the change. Fits for the models were similar with respect to the abundance indices, but differed to the extent they were able to track the change in age data from the population. All four models were able to track the very large increases and decreases seen in the acoustic indices and had similar overall fits (Figure 5). All four models also fitted the trajectory of mean age reasonably well, although models 1.2 and 1.4 were unable to fit the mean age in the last two years (Figure 6). The key difference between the four models is the strength of the 2002 year class, which ranged from about 8 in model 1.2 to 16 in model 1.3 (Figure 7). A further difference is the strength of the 2007 year class which is estimated to be about 5 in models 1.2 and 1.4 but only about 1 in the other two models.

Table 7: MPD estimates of equilibrium biomass (B_0) initial biomass ($B_{initial}$), current biomass (B_{2011}) and current biomass as a percent of B_0 for model runs 1.1, 1.2, 1.3, and 1.4.

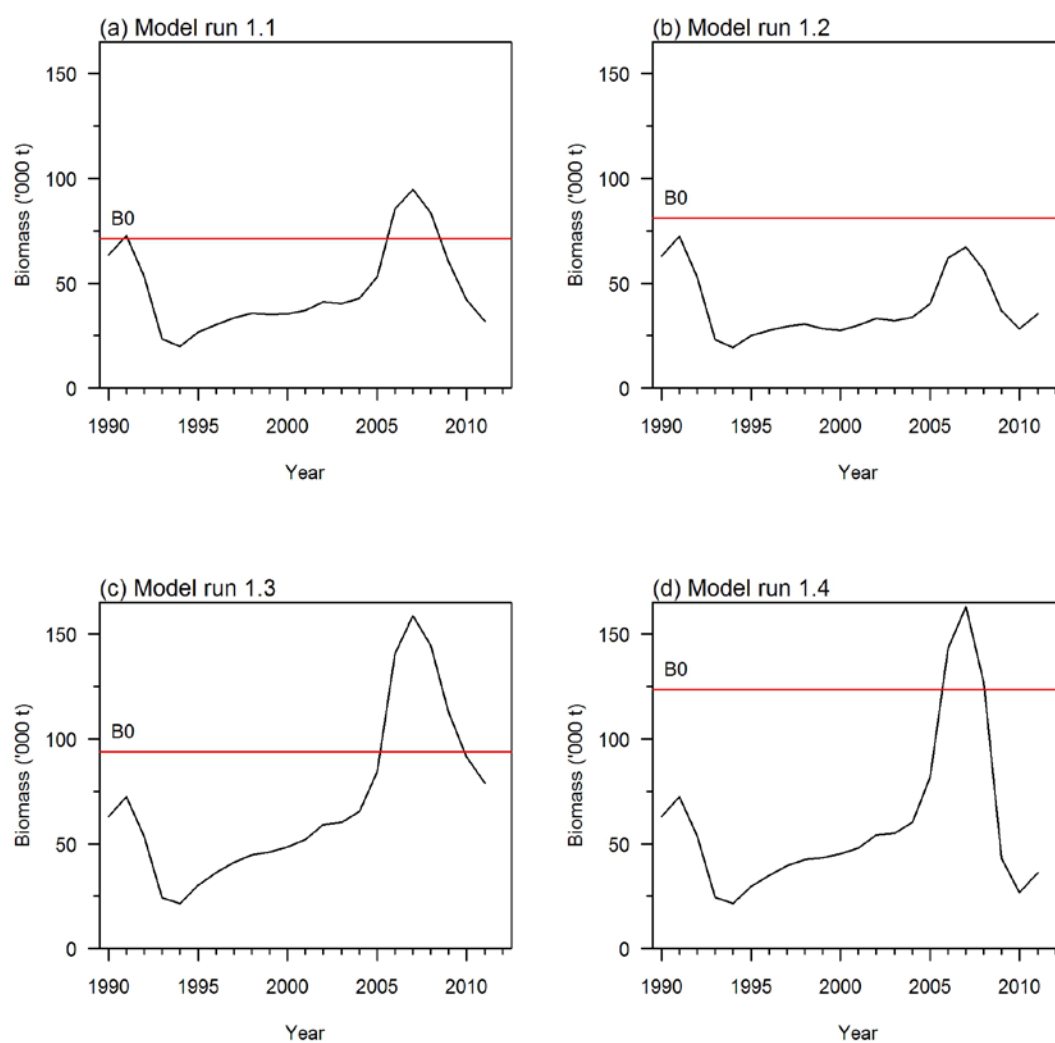| Model	B_0	B_{1990}	B_{2011}	B_{2011}/B_0 (%)
Model 1.1	71 311	63 403	31 823	44.6
Model 1.2	81 256	63 045	35 494	43.7
Model 1.3	93 956	62 793	79 074	84.2
Model 1.4	123 749	63 019	36 281	29.3

Figure 4: MPD estimates of mid-season spawning stock biomass for the models 1.1, 1.2, 1.3, and 1.4. the horizontal line represents B$_0$.
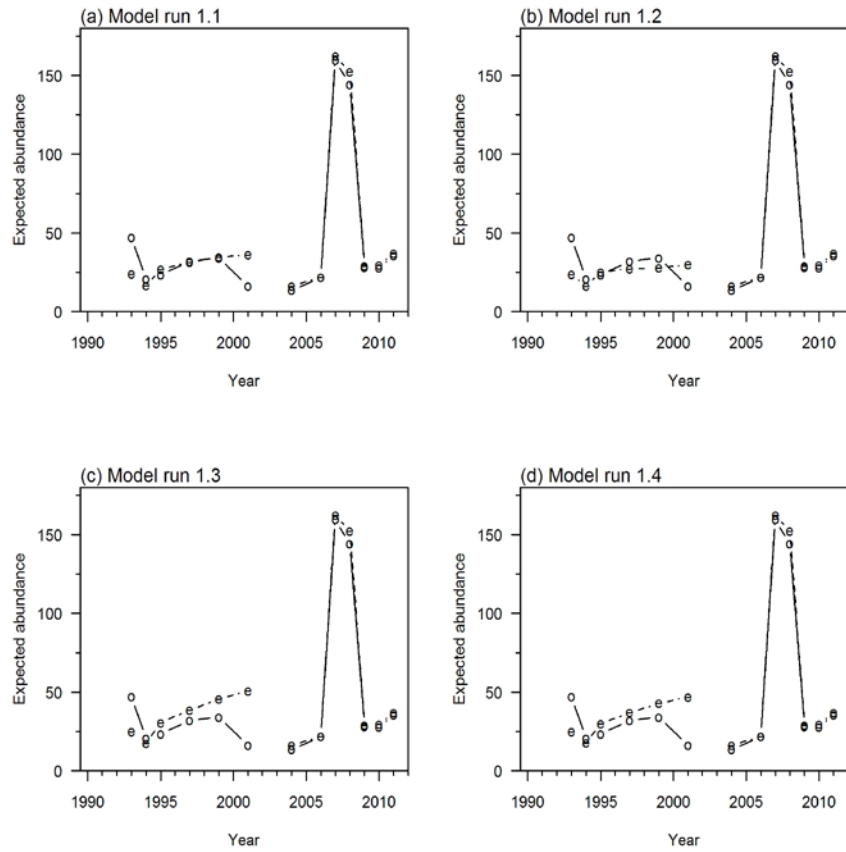
Figure 5: Observed (o) and expected (e) fits to the wide area and local area aggregation biomass indices for the models 1.1 – 1.4.
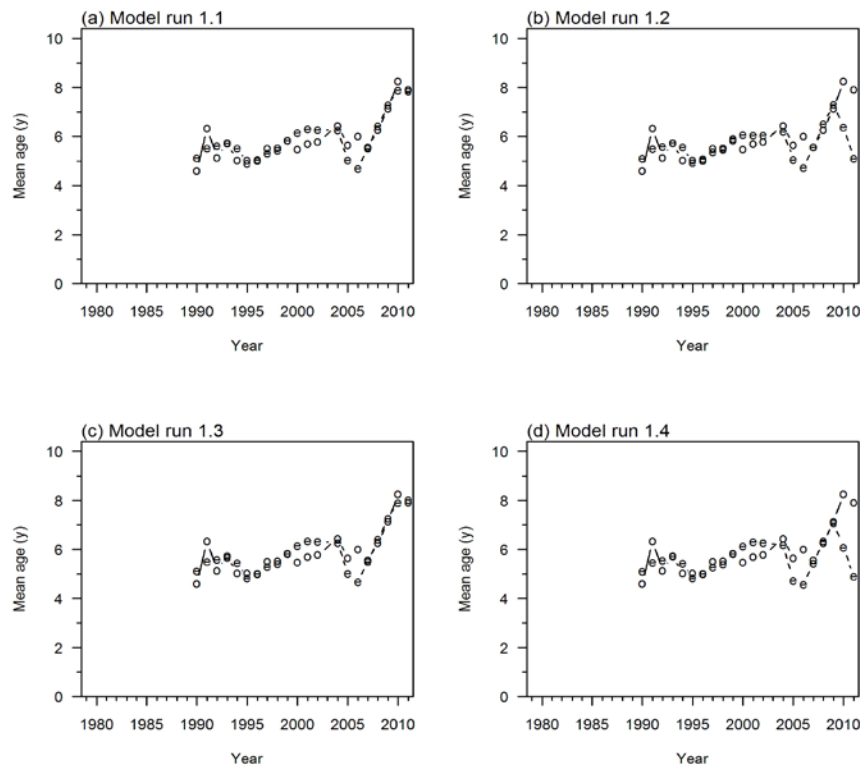

Figure 6: Observed (o) and expected (e) mean ages for models 1.1 – 1.4.
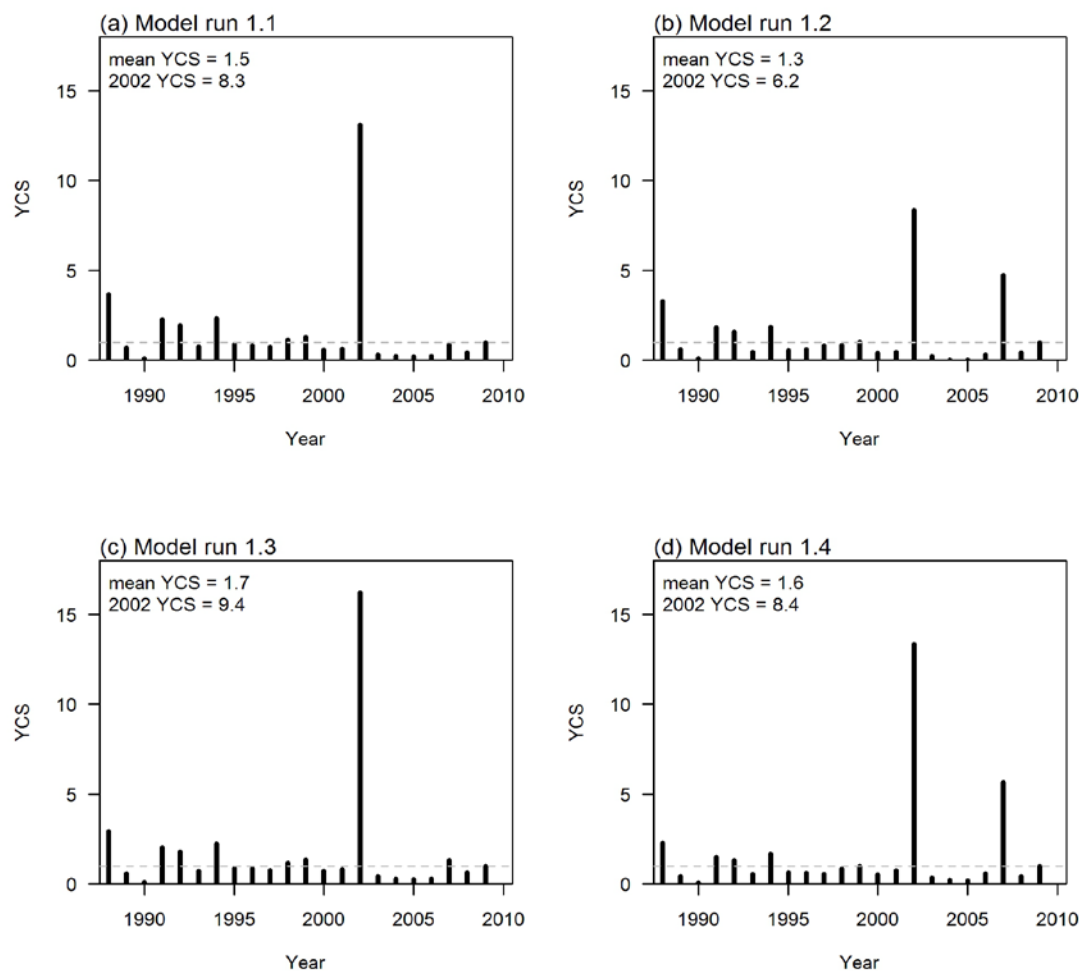
Figure 7: Estimated relative year class strengths in the models 1.1, 1.2, 1.3, and 1.4. Plots also show the mean of the year class strengths from the period 1988–2008 including the 2002 year class, and the equivalent 2002 year class multiplier assuming a mean of one for the period 1988–2008.

3.3 MCMC results

3.3.1 MCMC Diagnostics

MCMC diagnostics for the four models are shown in Figure 8–Figure 15. Trace plots for the key parameters (B_0 and B_{2011}) were generally consistent and showed little evidence of large scale correlation between iterations. Plots of median jump size, stationarity tests, and half-width tests all showed little evidence for poor convergence of the parameters in any of the models. Trace plots for stock status (B_{2011}/B_0) showed much less variability for models 1.2 and 1.4 than for models 1.1 and 1.3.
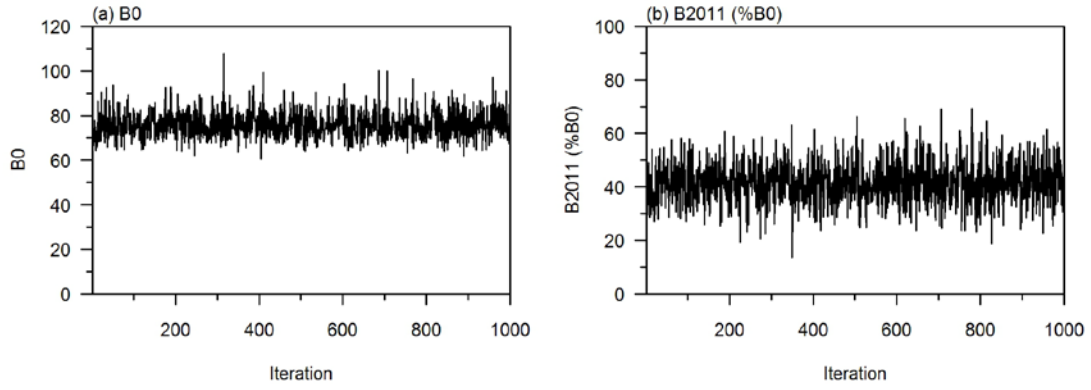
Figure 8: MCMC posterior trace plots for (a) B_0 and (b) current biomass (%B_{2011}/B_0) for model 1.1.

Figure 9: MCMC posterior diagnostic plots for model 1.1, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for B_0.

Figure 10: MCMC posterior trace plots for (a) B_0 and (b) current biomass (%B_{2011}/B_0) for model 1.2.
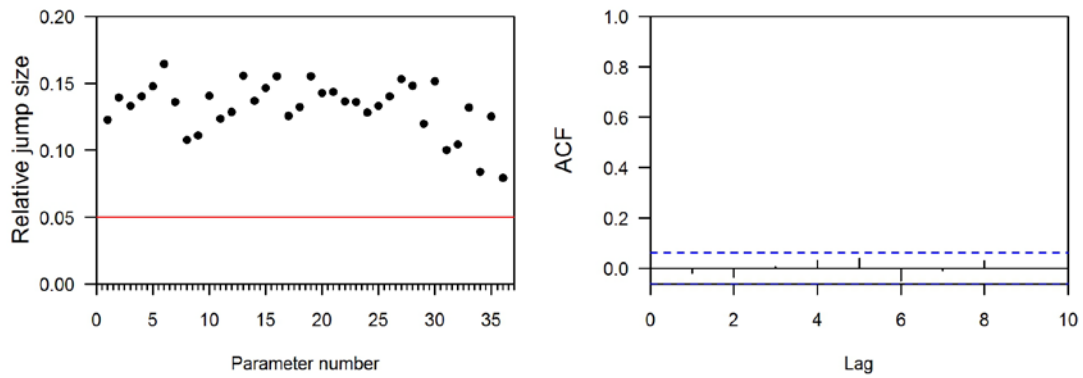
Figure 11: MCMC posterior diagnostic plots for model 1.2, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for B_0.
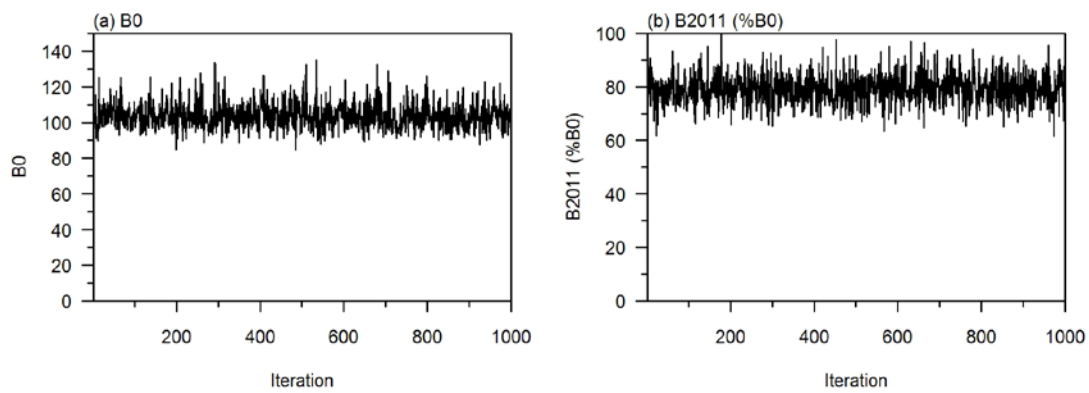
Figure 12: MCMC posterior trace plots for (a) B_0 and (b) current biomass (%B_{2011}/B_0) for model 1.3.

Figure 13: MCMC posterior diagnostic plots for model 1.4, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for B_0.
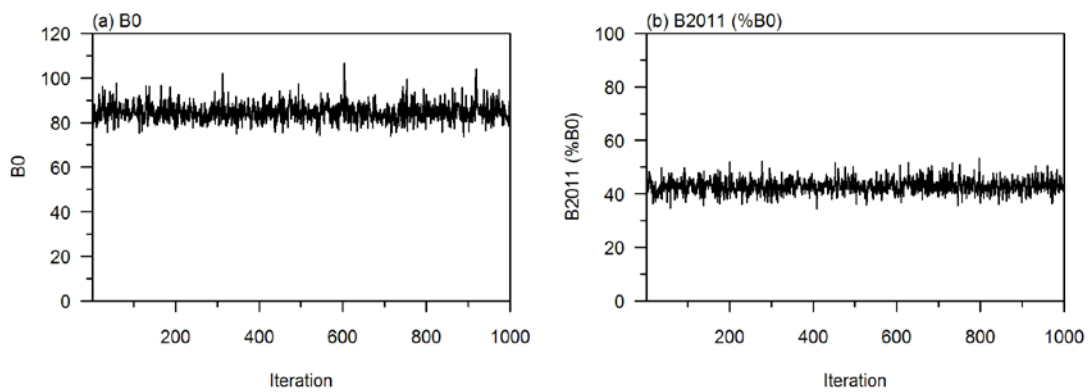
Figure 14: MCMC posterior trace plots for (a) B_0 and (b) current biomass ($\%B_{2011}/B_0$) for model 1.4.
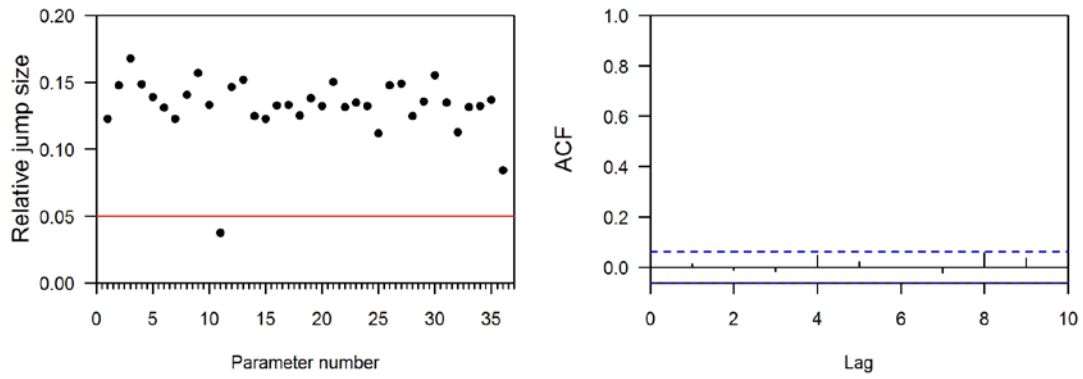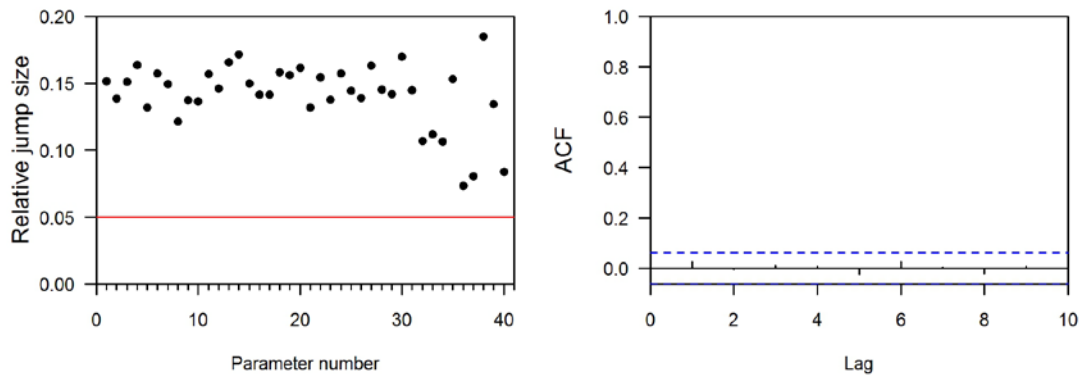

Figure 15: MCMC posterior diagnostic plots for model 1.4, showing (left) median relative jump size for all parameters (x-axis, labelled 1–37), and (right) autocorrelation lag plot for B_0.
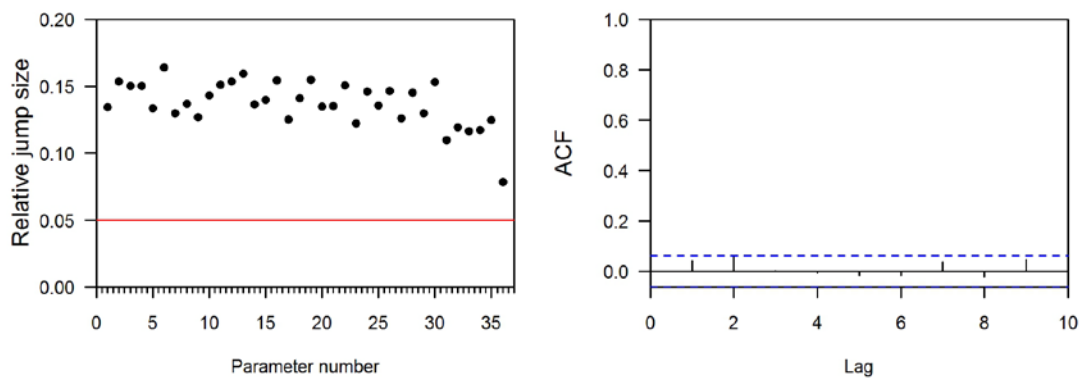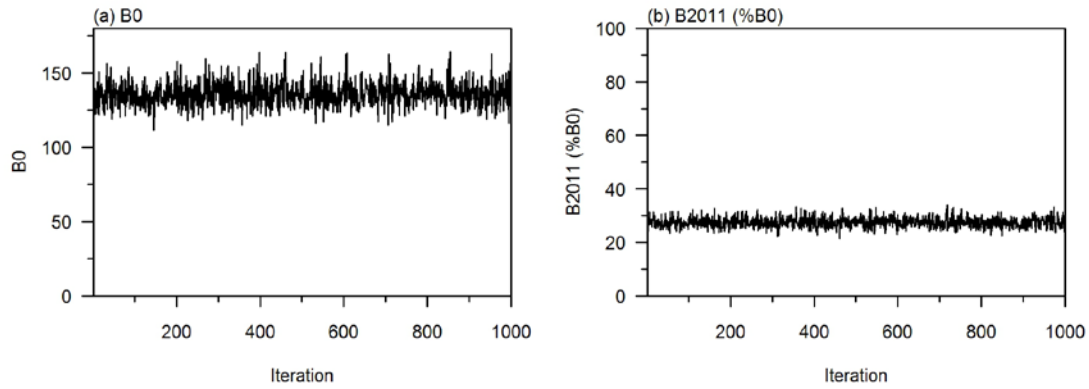
3.3.2 MCMC estimates

MCMC posterior plots for B_0 and current biomass ($\%B_{2011}/B_0$) are shown for the four models in Figure 16–Figure 19 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 quite different between models and ranged from 75 000 to 135 000 t. Estimates of B_0 from models 1.3 and 1.4 were substantially higher than the estimates from the other two models.

Median estimates of B_{2011} were also different between models, ranging from 31 000 to 81 000 t. The highest estimates of B_{2011} came from model run 1.3, where the q in 2007 and 2008 was constrained to be similar to the wide area 4+ index. The other three models were much more similar with estimates of B_{2011} ranging from 31 000 to 37 000 t. The 95% confidence intervals were unrealistically tight for models 1.2 and 1.4.

Estimates of the catchability coefficients (q) for all the acoustic indices for the model runs are summarised in Table 9. In order to fit the various acoustic local area aggregation surveys the estimates of q from the individual aggregation surveys ranged from 0.15 to 2.77 across the various model runs and surveys fitted. Even within a single model run the range of estimated qs was still very wide – ranging from a 4-fold difference in model 1.3 to an 8-fold difference in model 1.2. It is hard to believe that an acoustic survey could overestimate the abundance of fish by a large amount, and so on the basis of the acoustic q the model runs 1.1 and 1.2 are judged to be less likely.

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

Model	B_0	B_{2011}	B_{2011} (%B_0)
Model 1.1	75 320 (65 520–89 320)	31 089 (18 101–49 590)	41 (26–58)
Model 1.2	84 230 (76 890–93 860)	35 998 (31 776–41 413)	43 (37–49)
Model 1.3	103 290 (91 110–121 340)	81 449 (69 543–98 832)	79 (68–91)
Model 1.4	135 270 (120 920–153 840)	37 148 (32 735–43 137)	27 (24–32)

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

Parameter				Model
	Model 1.1	Model 1.2	Model 1.3	Model 1.4
Tangaroa (age 2) q	0.94 (0.79–1.13)	1.44 (1.24–1.68)	0.72 (0.61–0.85)	0.76 (0.64–0.89)
Tangaroa (age 3) q	1.27 (1.05–1.55)	1.49 (1.24–1.78)	0.99 (0.82–1.18)	1.03 (0.84–1.27)
Tangaroa (age 4+) q	1.00 (1.00–1.00)	1.00 (1.00–1.00)	1.00 (1.00–1.00)	1.00 (1.00–1.00)
Local area 2004 q	0.36 (0.27–0.46)	0.47 (0.39–0.58)	0.23 (0.19–0.28)	0.24 (0.20–0.30)
Local area 2006 q	0.26 (0.21–0.33)	0.36 (0.33–0.41)	0.16 (0.14–0.17)	0.15 (0.13–0.17)
Local area 2007 q	1.81 (1.46–2.20)	2.52 (2.37–2.71)	1.04 (0.97–1.11)	1.02 (0.92–1.12)
Local area 2008 q	1.90 (1.51–2.36)	2.77 (2.59–2.80)	1.06 (0.99–1.14)	1.20 (1.11–1.31)
Local area 2009 q	0.51 (0.39–0.66)	0.80 (0.74–0.86)	0.26 (0.24–0.28)	0.68 (0.63–0.74)
Local area 2010 q	0.74 (0.52–1.08)	1.09 (1.01–1.18)	0.33 (0.29–0.36)	1.17 (1.08–1.27)
Local area 2011 q	1.20 (0.77–2.04)	1.04 (0.94–1.14)	0.46 (0.38–0.53)	1.00 (0.91–1.10)
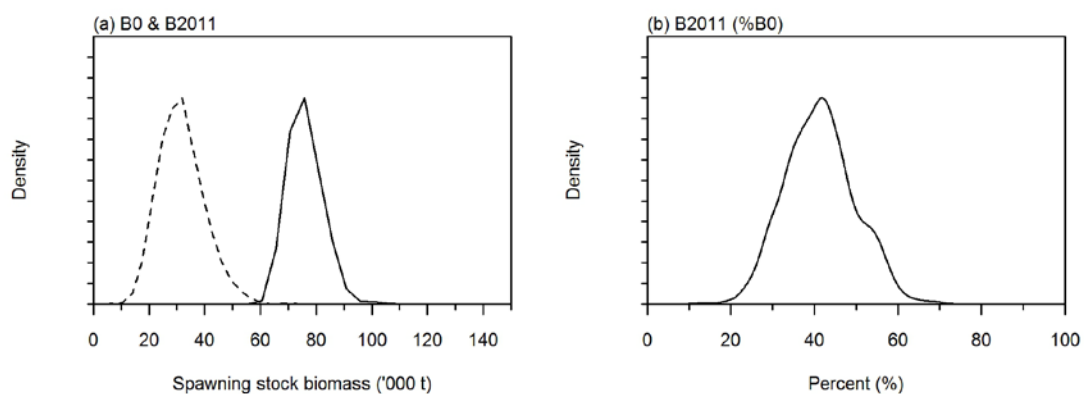
Figure 16: MCMC posterior plots for (a) B_0 (solid line) and B_{2011} (dashed line) and (b) current biomass (%B_{2011}/B_0) for model 1.1.
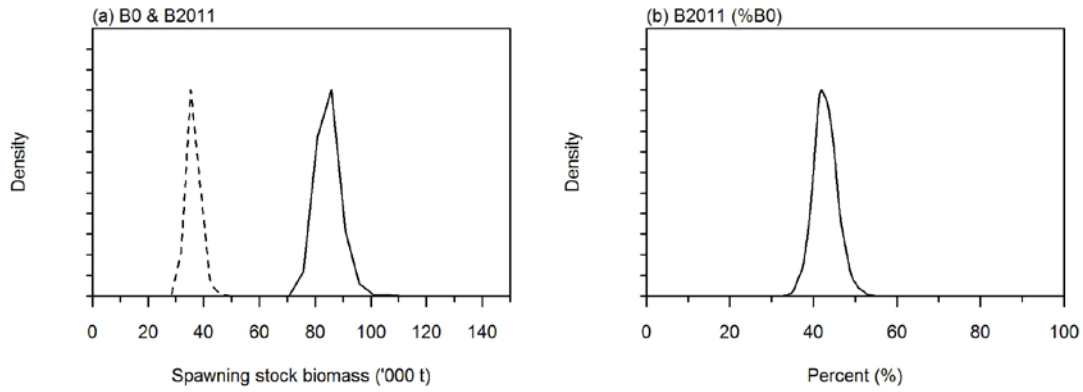
Figure 17: MCMC posterior plots for (a) B_0 and B_{2011} (dashed line) and (b) current biomass (%B_{2011}/B_0) for model 1.2.
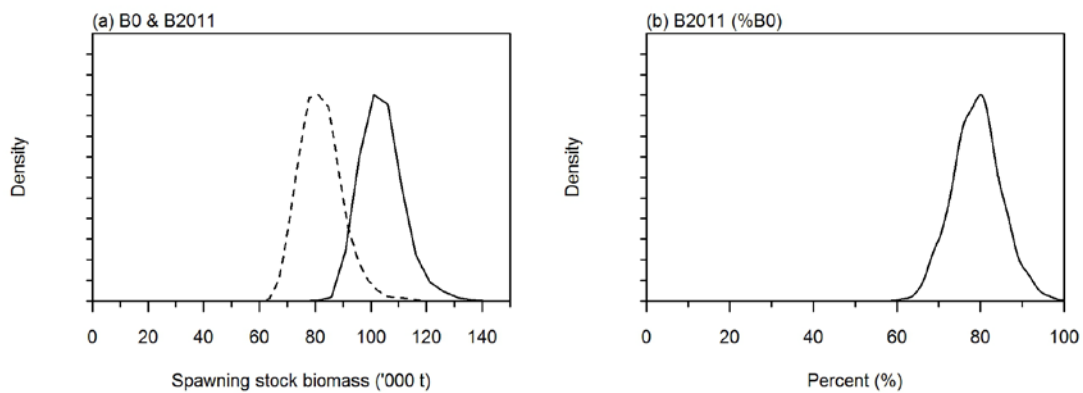
Figure 18: MCMC posterior plots for (a) B_0 and B_{2011} (dashed line) and (b) current biomass (%B_{2011}/B_0) for model 1.3.
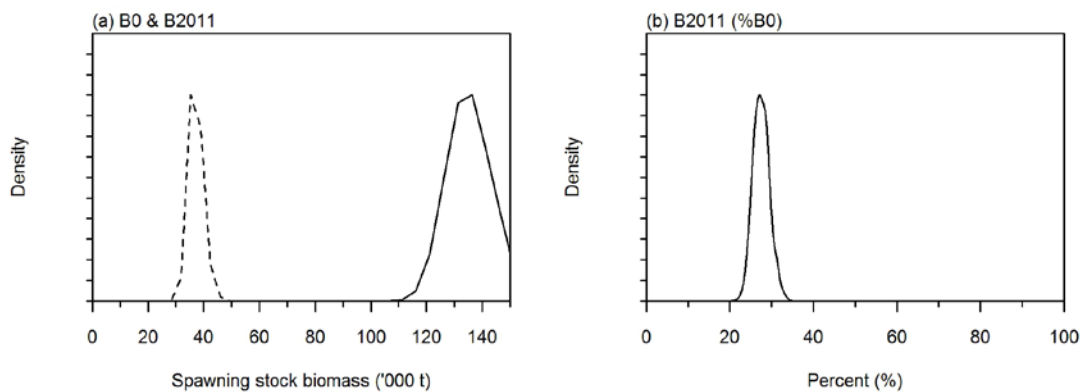
Figure 19: MCMC posterior plots for (a) B_0 and B_{2011} (dashed line) and (b) current biomass (%B_{2011}/B_0) for model 1.4.

3.4 Projections

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 model run 1.3 for all years (Table 10). However, the probability that the mid-season biomass will be less than the threshold level for model 1.1 is greater than 10% for all years, for model 1.4 it is greater than 10% for 2013 onwards and for model run 1.2 it is greater than 10% for 2014 onwards. Under average recruitment

conditions the models predicted that biomass is expected to decrease after 2011 under a catch of 15 000 t, and, in all scenarios, is expected to be below 50% B_0 by 2015 (Figure 20). For three of the four models the median biomass was projected to be below 20% by 2015.

Table 10: Probability that the projected mid-season vulnerable biomass for 2012–2015 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 1.1, 1.2, 1.3, and 1.4.

Catch	Model	Pr (SSB < 0.2B_0)				Median SSB (%B_0)			
		2012	2013	2014	2015	2012	2013	2014	2015
15 000 t	Model 1.1	0.12	0.58	0.76	0.84	30.6	17.4	11.0	8.6
	Model 1.2	0.00	0.04	0.45	0.68	43.0	31.2	21.8	13.7
	Model 1.3	0.00	0.00	0.00	0.02	70.4	59.7	52.2	46.2
	Model 1.4	0.00	0.20	0.43	0.54	29.9	25.1	22.0	18.7

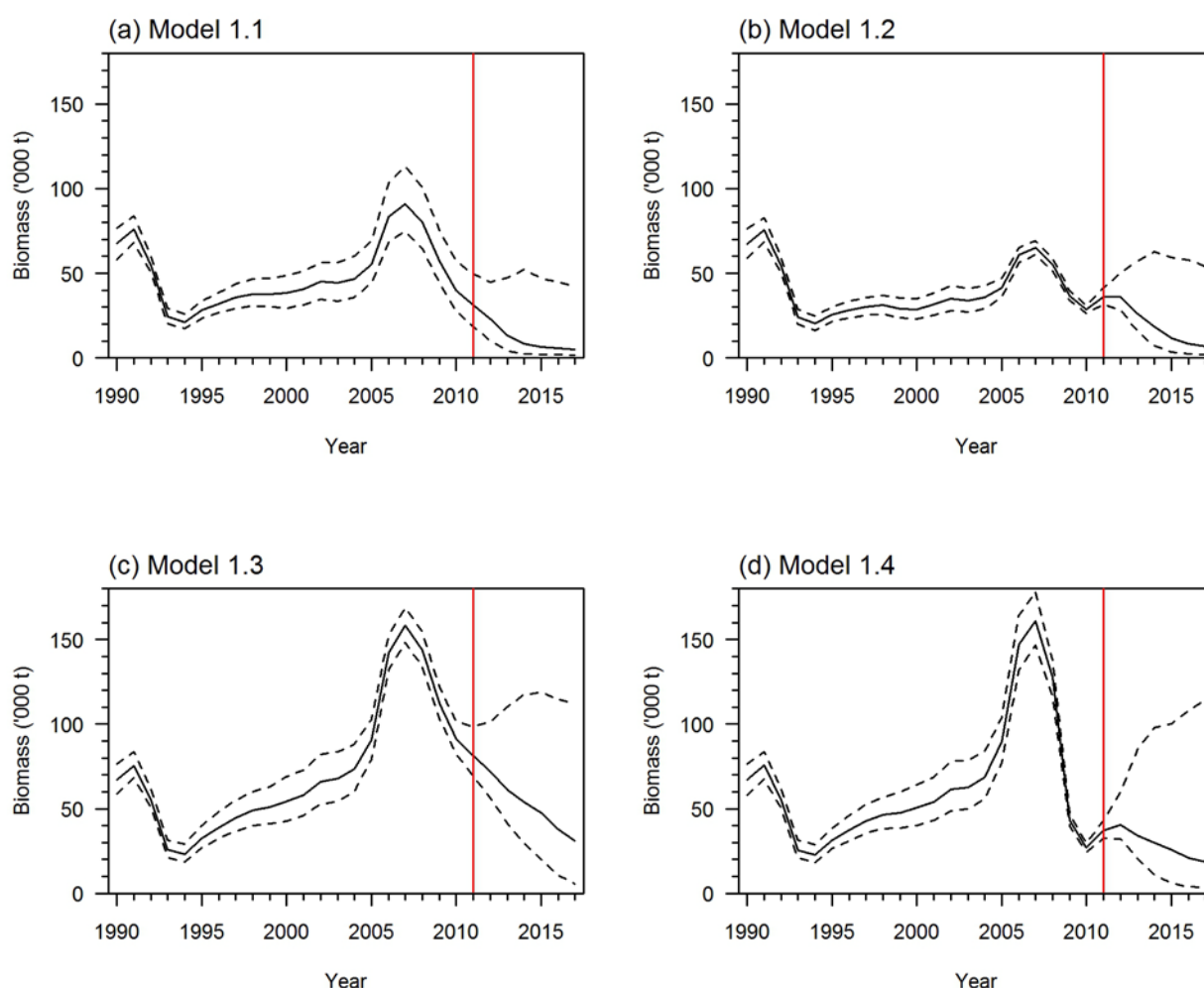**Figure 20: MCMC posterior plots for the median (solid line) and 95% credible intervals (dashed lines) for B_0 for models 1.1 to 1.4. The vertical line represents the beginning of the projection period (2012–2015).**

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 2005). Surveys were carried out in each of the years 2004–2011, but the surveys had mixed levels of success. There was also some concern that the surveys in 2006 and 2009 did not sample the entire aggregation because on several transects the fish marks extended beyond the area being surveyed (O'Driscoll et al. 2006). Recent stock assessments have been unable to reconcile the very sharp increase and subsequent decrease in adult biomass seen through the series with the observed proportions-at-age in the commercial fishery (Hanchet & Dunn 2009a, 2009b, Dunn & Hanchet 2011). In this assessment we were only able to reconcile these conflicting data sources by freeing up assumptions of constant catchability between the aggregation surveys, by fixing the wide area age 4+ acoustic q at 1.0, 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 surveys 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 are extremely uncertain. The four model runs provided a range of possible estimates of B_{2011} ranging from 31 000–81 000 t. Although the MPD fits to the acoustic indices for all the runs looked reasonable, runs 1.2 and 1.4 were unable to fit recent age data. On the other hand, estimates of the adult acoustic q were higher than might be considered plausible for several surveys for model runs 1.1 and 1.2.

Because of the problems with the stock assessment, essentially arising from difficulties in fitting the aggregation survey data, the stock assessment results were not used for providing management advice. Instead, the Middle Depths Working Group agreed to provide a catch limit for the 2012–13 season based on a proxy yield calculated by multiplying the 2011 acoustic survey estimate by the U_{CAY} exploitation rate (see also Appendix 2). Estimates of yield from that method ranged from 1800 t to 18 800 t, with a mean of 6500 t.

The key uncertainty with the current stock assessment is the treatment of the aggregation surveys because the overall proportion of the adult biomass sampled by each survey is unknown. We recommend that a wide area survey be carried out so that a snapshot of total adult biomass can be obtained.

5. ACKNOWLEDGEMENTS

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APPENDIX A

Table A1: Assumed mean length (cm) at age for male southern blue whiting aged 2–11+, 1990–2011, and the assumed mean length at age for projections, 2012–2016 (grey highlight).

Year										Age
	2	3	4	5	6	7	8	9	10	11+
1990	26.8	32.3	35.5	38.0	42.6	45.0	45.5	44.1	46.5	48.1
1991	29.0	32.3	35.3	39.0	44.5	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	42.5	47.0	48.3	47.5	48.4
1994	27.8	32.1	36.0	38.2	40.6	43.8	43.9	49.0	48.5	49.1
1995	28.8	31.1	35.4	37.3	40.3	41.9	43.8	45.2	51.0	48.6
1996	25.4	32.2	34.1	37.8	38.0	41.3	43.7	44.9	48.0	49.0
1997	27.3	31.4	34.9	36.4	39.1	43.0	42.7	44.4	45.8	50.7
1998	28.2	30.8	32.5	36.1	37.7	40.7	45.0	45.1	46.2	47.4
1999	28.8	32.0	34.9	35.3	38.9	40.0	42.2	47.0	45.5	46.9
2000	26.8	33.1	35.4	38.9	39.7	41.8	42.9	44.2	48.0	45.6
2001	28.7	32.5	36.2	38.5	41.5	39.7	42.0	45.0	47.0	49.6
2002	27.3	32.9	36.1	39.2	41.1	42.0	42.3	43.4	46.8	49.1
2003	32.8	30.9	35.9	38.3	41.1	42.8	42.2	43.2	44.2	48.5
2004	25.7	37.0	37.8	40.8	41.6	43.1	44.9	44.0	45.0	45.6
2005	27.8	29.0	38.1	39.8	41.0	42.4	44.0	45.0	45.0	46.7
2006	28.9	30.8	32.3	38.6	41.4	42.7	43.6	44.4	45.4	46.4
2007	28.2	30.0	33.6	34.5	38.7	42.8	44.8	44.5	47.1	45.4
2008	29.3	31.8	33.0	34.7	36.4	38.8	43.0	45.3	46.7	47.5
2009	27.3	30.5	32.7	35.0	35.0	37.0	42.2	45.0	46.0	46.7
2010	27.8	30.2	34.0	33.0	36.0	35.4	38.0	43.0	46.0	46.3
2011	27.2	31.9	33.6	35.8	34.6	37.5	43.3	38.7	43.0	43.4
2012	27.8	30.8	35.4	35.9	37.5	36.2	38.8	44.5	39.4	44.6
2013	27.8	31.5	34.2	37.8	37.6	39.2	37.4	39.8	45.3	40.9
2014	27.8	31.5	35.0	36.5	39.6	39.3	40.6	38.4	40.6	47.0
2015	27.8	31.5	35.0	37.3	38.2	41.3	40.6	41.6	39.1	42.1
2016	27.8	31.5	35.0	37.3	39.1	40.0	42.8	41.7	42.4	40.6

Table A2: Assumed mean length (cm) at age for male southern blue whiting aged 2–11+, 1990–2011, and the assumed mean length at age for projections, 2012–2016 (grey highlight).

Year	2	3	4	5	6	7	8	9	10	Age 11+
1990	26.5	30.8	38.1	43.7	45.0	47.0	49.6	50.0	53.6	53.4
1991	26.0	33.2	37.3	41.6	46.3	45.8	50.5	50.5	52.9	54.0
1992	29.0	33.8	37.3	41.8	43.8	47.4	50.6	51.5	51.5	54.0
1993	27.3	37.0	37.6	40.5	43.2	46.0	49.8	51.8	52.4	53.9
1994	30.1	33.9	40.5	41.1	43.0	46.4	48.2	52.6	53.0	53.2
1995	31.1	32.6	37.7	41.5	44.4	45.2	48.6	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	25.8	33.3	38.0	38.2	42.5	44.7	48.3	48.4	50.2	53.5
1998	29.6	30.9	34.0	39.4	39.9	44.2	46.5	48.4	49.5	53.1
1999	30.0	34.0	35.6	37.8	40.9	42.9	45.6	47.6	48.9	51.4
2000	27.1	34.0	36.5	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	28.7	34.7	38.7	42.4	43.7	45.2	47.9	48.9	50.9	55.0
2003	28.7	36.3	38.0	42.6	43.9	45.7	47.7	49.1	49.9	53.2
2004	25.0	33.9	39.6	42.8	44.1	47.0	46.8	49.1	49.8	51.0
2005	28.7	29.9	37.0	42.0	44.2	44.9	48.0	49.0	50.0	51.0
2006	29.0	31.2	33.4	41.0	44.2	45.5	47.2	48.4	51.2	50.5
2007	27.2	31.8	34.0	36.3	41.0	44.6	48.1	48.9	49.4	52.2
2008	25.6	32.6	34.6	34.0	38.4	41.0	45.8	48.8	49.1	52.1
2009	27.9	30.7	32.6	35.0	35.2	39.1	23.0	47.0	49.0	51.6
2010	28.7	33.9	32.5	36.0	35.2	34.5	40.5	43.5	47.4	50.7
2011	29.2	33.1	34.9	40.6	42.1	44.7	40.0	41.6	43.4	50.0
2012	27.9	34.9	36.5	38.4	42.5	44.9	47.5	41.2	42.8	45.5
2013	27.9	33.3	38.4	40.2	40.2	45.4	47.7	48.9	42.4	44.9
2014	27.9	33.3	36.7	42.3	42.0	43.0	48.2	49.2	50.3	44.5
2015	27.9	33.3	36.7	40.4	44.3	44.9	45.6	49.7	50.6	52.8
2016	27.9	33.3	36.7	40.4	42.3	47.3	47.7	47.0	51.1	53.0

APPENDIX B

Estimates of a proxy yield based on an absolute biomass estimate of SBW on the Bounty Platform (SBW 6B)

An alternative method of determining a yield of SBW may be to assume that the estimate of biomass from the 2011 local area aggregation acoustic survey is an absolute estimate of abundance, and hence used to estimate a proxy CAY yield (Ministry of Fisheries 2011).

Here, it is assumed that the expected biomass (B_i) in the year following the survey can be calculated from the appropriate survey biomass ($\hat{B}_{i-1}$), after accounting for any catch (C_{i-1}), natural mortality (M), change in mean weight (w), and recruitment (R_i), i.e.,

$$B_i = \frac{w_i}{w_{i-1}}\left(\hat{B}_{i-1} - 0.5C_{i-1}\right)e^{-M} + R_i$$

Assuming that an appropriate exploitation rate (U) for southern blue whiting is 0.20 (Ministry of Fisheries 2011) and assuming that the combined effect on the biomass in the year following the survey from recruitment, change in mean weight, and natural mortality is negligible, the yield can be calculated as,

$$Y_i = 0.2\left(\hat{B}_{i-1} - 0.5C_{i-1}\right)$$

Using the acoustic survey biomass estimate from 2011 (see Table 5) as an estimate of the midseason vulnerable biomass, and assuming lognormally distributed errors an estimate of the expected yield, and the upper and lower bounds in this estimate, can be calculated. It was assumed that the 80% quantiles (i.e., the 10th and 90th percentiles) and the uncertainty in the target strength of southern blue whiting is ±3 dB (which approximates to a doubling or halving of the resulting biomass calculated from the target strength relationship) represent adequate bounds on the uncertainty in the acoustic estimates

Further, it was assumed that the combined effects of recruitment, the increase or change in mean weight from the growth of individuals, and natural mortality over a one year time frame are negligible and can be ignored. Is this assumption valid? It is noted that a natural mortality rate of 0.2 y^{-1} would be expected to reduce the biomass by 18% each year. The increase in mean weight (assuming 1 cm of growth for fish with a mean size of 39 cm) would be expected to increase biomass by about 8% in one year. Recruitment is unknown, but assumed to be about average. While there has been evidence of negligible recruitment since the strong 2002 year class, there was some indication of an average year class for 2007 (4 year olds) in the catch in 2011 (see Figure 3). Therefore, for a one year projection it is probably a valid assumption.

Table B1 gives the absolute estimates of southern blue whiting biomass from the 2011 local area aggregation acoustic survey along with the 80% intervals and the ±3 dB uncertainty in the biomass estimate. The yields calculated from the biomass estimates in Table B1 using the equation above and assuming that the total catch taken in 2011 was 6590 t are given in Table B2.

Table B1: Absolute 80th percentile estimates of midseason southern blue whiting biomass (±3 dB) from the 2011 local area aggregation acoustic survey, ignoring any corrections for the potential bias in the catchability coefficient, q.

Year	TS multiplier	Biomass estimate		
		10th percentile	Mean	90th percentile
2011	0.5	12 050	17 800	24 370
	1.0	24 110	35 600	48 750
	2.0	48 210	71 190	97 490

Table B2: Approximate proxy yields for southern blue whiting in 2012, using the 2011 local area aggregation acoustic survey and assuming the combined effect on the biomass in the year following the survey from recruitment, change in mean weight, and natural mortality is negligible; and ignoring a correction for the potential bias in the catchability coefficient, q.

Survey year	Yield year	TS multiplier	Yield estimate		
			10th percentile	Mean	90th percentile
2011	2012	0.5	1 752	2 901	4 216
		1.0	4 162	6 460	9 090
		2.0	8 983	13 580	18 839