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Southern blue whiting (*Micromesistius australis*) stock assessment for the Campbell Island Rise for 2016
New Zealand Fisheries Assessment Report 2017/38

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EXECUTIVE SUMMARY

This report documents an update of stock assessment modelling for the Campbell Island Rise stock of southern blue whiting, covering the period 1979–2015 and using the input data catch history, proportion-at-age, and acoustic survey biomass estimates up to and including the 2015 fishing season. The primary data sources were the relative abundance index from the R.V. *Tangaroa* wide-area acoustic biomass surveys carried out from 1993 to 2013, and proportion-at-age data from 1979 to 2015.

The results of the base case assessment model run suggested that the biomass of the Campbell Island Rise stock in 2015 was 220 200 t (95% C.I.s 141 700–323 400 t), and was at 62% B_0 (95% C.I.s 46–79%). The biomass was expected to decline to 41% B_0 by 2018 under an assumption of a constant catch equal to the current TAC in 2015 (40 000 t). The assessment was strongly influenced by the high biomass estimates from the last three acoustic surveys in 2009, 2011 and 2013.

The median estimates of B_0 were higher than those from the 2013 assessment, and higher than earlier estimates of B_0 from this stock. This was primarily due to the strong 2006, 2009, and 2011 year classes which had entered the fishery. There was little doubt that these year classes were strong, although not as strong as the previous large 1991 year class, and that the increase in biomass observed in recent years was due to the recruitment of these strong year classes.

1. INTRODUCTION

Around New Zealand, 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 are 35–50 cm fork length (FL), although occasionally smaller length classes of males (29–32 cm FL) have been observed in the catch (Dunn & Hanchet 2016).

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 generally been smaller fisheries, with much lower annual catches than the Campbell Island Rise and Bounty Platform fisheries (Dunn & Hanchet 2016).

Acoustic biomass surveys using R.V. *Tangaroa* of the Campbell Island Rise stock have been carried out approximately every two to three years since 1993 and the most recent survey was carried out in 2013 (O'Driscoll et al. 2013). Stock assessments of the Campbell Island Rise stock have been carried out every one or two years since 1991 with the most recent assessment completed for the 2013–14 fishing year (Dunn & Hanchet 2015).

This report documents the assessment of the Campbell Island Rise stock using data up to and including the 2015–16 fishing year (2015 season). We update the assessment using the R.V. *Tangaroa* acoustic biomass indices for 1993–2013 and commercial catch proportions-at-age data from the years 1979–2015. The acoustic indices were calculated using the revised target strength derived by O'Driscoll et al. (2013). . A comprehensive summary of available data used for the assessments of southern blue whiting was described by Dunn & Hanchet (2016).

This report is in fulfilment of the Ministry for Primary Industries Project DEE201508 (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 Campbell Island stock, including estimating biomass and sustainable yields).

2. METHODS

2.1 Population dynamics

A two-sex, single stock and single area Bayesian statistical catch-at-age model for the Campbell Island Rise southern blue whiting stock was implemented in CASAL (Bull et al. 2012) following a similar approach to that used in previous assessments of this stock (e.g., Dunn & Hanchet 2015). The model partitioned the stock into immature and mature fish with two sexes and age groups 2–15, with a plus group at age 15. The models were run for the years 1979 to 2015. Five-year projections were run for the years 2016–2020. 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 matured, ages were incremented, and the 2-year-olds were recruited to the population. These were then subjected to fishing mortality and the remaining 10% of natural mortality. A two-sex model was assumed because there are sex-based differences in both the proportions-at-age in the commercial catch for fish aged 2–4 (see later) and their mean length at age (Dunn & Hanchet 2016).
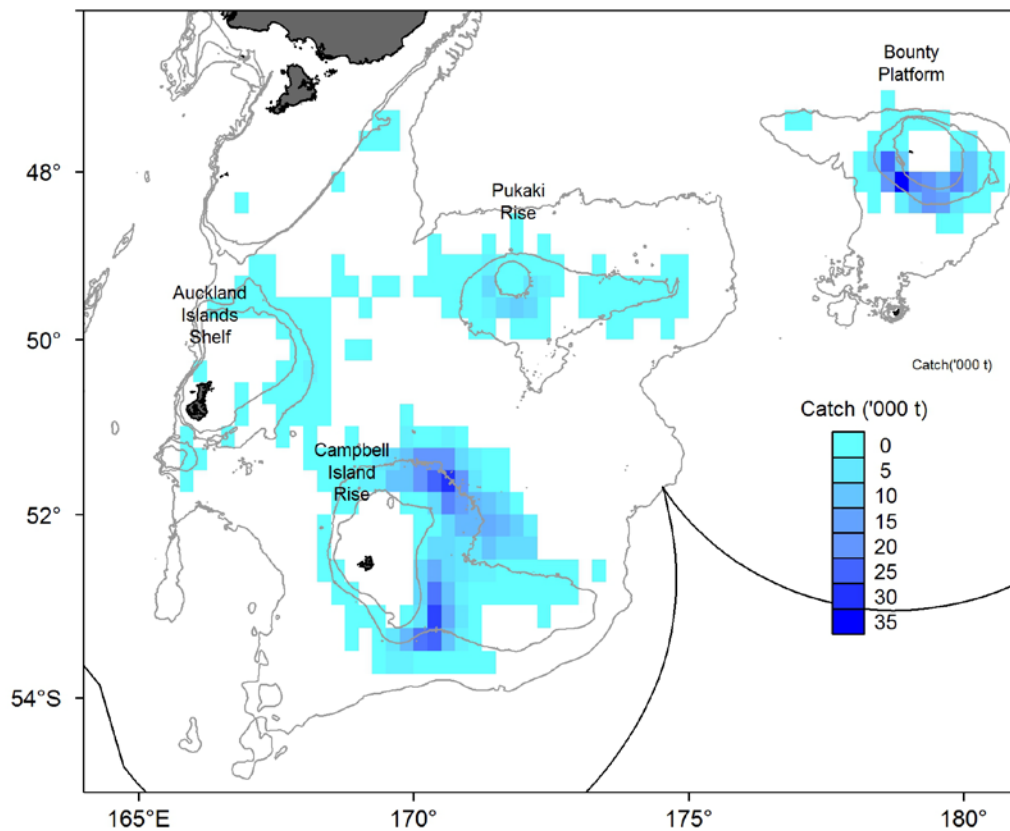
Figure 1: Relative total density of the commercial catch of southern blue whiting by location, TCEPR data 1990–2015.

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. Relative year class strengths for the years 1977–2012 were parameterised in the model such that the mean for the years 1977–2012 was equal to one.

Southern blue whiting on the Campbell Island Rise are assumed to be mature when on the fishing ground, as they are fished during spawning (Dunn & Hanchet 2016). Hence, it was assumed that all mature fish were equally selected by fishing. The maximum exploitation rate (U_{max}) was assumed to be 0.8. The proportion of immature fish that mature in each year was estimated for ages 2–5, with fish aged 6 and above assumed to be fully mature (see Dunn & Hanchet 2015 and previous assessments).

Southern blue whiting exhibit large inter-annual differences in growth, presumably caused by local environmental factors, closely correlated with the occurrence of the strong and weak year classes (Dunn & Hanchet 2016). Hence, we did 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. The length-at-age matrix used the empirically estimated mean lengths-at-age from the commercial catch data (Dunn & Hanchet 2016). 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. For projections, the mean sizes-at-age were assumed to be equal to the estimated sizes-at-age in 2015.

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 $= a \times$ 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 for all model years.

Catches for southern blue whiting have been recorded since 1971 (Dunn & Hanchet 2016), with an average of 25 000 t annual catch between 1971 and 1977 (Figure 2). However, the locations and hence the stock associated with the catch in this period is not well known. In addition, age and length sampling of the population from 1979 showed evidence of a very high proportion (greater than 50% by number in the catch proportions-at-age) of old fish (11+) in the Campbell Island Rise population, with the age data suggesting that there was at least one very strong year class spawned in or around 1965 that remained a significant part of the population until the mid-1980s (see also Hanchet et al., 1998).

Without accurate knowledge of the actual catch before 1978, and with strong evidence that the population was not at an equilibrium age structure, we assume a non-equilibrium age structure as the initial state. Hence, the population model was initialised with a starting state, labelled $C_{initial}$, in 1979. The numbers of individuals in the population at the start of the model were estimated for each age group (with both sexes combined) as independent parameters (see $C_{initial}$ in Bull et al. 2012 for details). Although the fishing selectivity on southern blue whiting differs at ages 2–4 between males and females, and the values of natural mortality may differ slightly between sexes, we assume that these differences will have little effect on the relative proportions of males and females in each age class in the population in 1979. Hence, we constrained the estimates of the initial age structure so that the number of males and females within each age class were equal.

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. Column headed M is the 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	Proportions at age Acoustic abundance indices

2.2 Observations

Available observations for the Campbell Island Rise stock are described in Dunn & Hanchet (2016). They include a time series of catches; wide area acoustic biomass estimates, survey age frequency data for immature fish; and proportions-at-age from the commercial catch.

Previous models have also considered CPUE indices and trawl survey biomass indices. Standardised CPUE indices were last updated by Hanchet et al. (2006) but were not considered to be a useful index of abundance by the Middle Depths Working Group. Hence, we have not used these data in this assessment.

Dunn & Hanchet (2011) modelled observations from the sub-Antarctic trawl survey biomass and age frequencies time series. They found that, although the model fits suggested some consistency with the summer series biomass estimates, in general the trawl survey underestimated biomass at low stock sizes and overestimated biomass at high stock sizes. They concluded that the time series was not particularly useful for monitoring abundance in its present form. Hence, we ignore these data for this assessment.
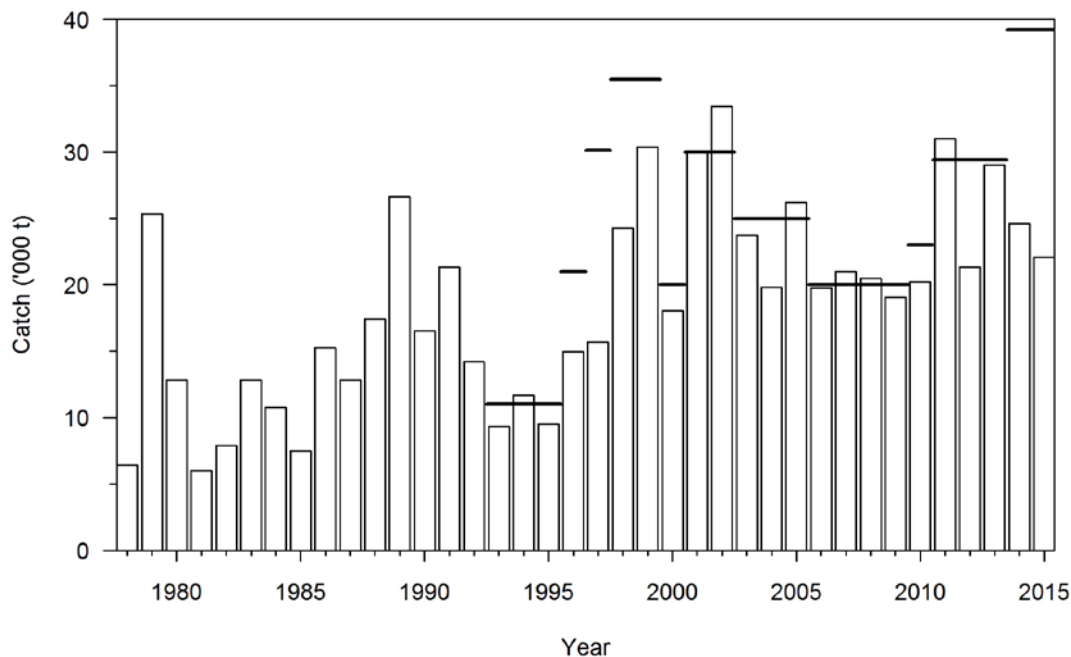
Figure 2: Reported landings of southern blue whiting on the Campbell Island Rise, 1978–2015. Horizontal lines indicate the TACC since it was first introduced in 1993.

2.2.1 Wide area acoustic surveys

Acoustic biomass estimates of southern blue whiting available on Campbell Island Rise during the fishing season were available from a wide area survey series conducted by the R.V. *Tangaroa* from 1993 to 2013 (see Table 2 and Dunn & Hanchet 2016 for details). The primary objective of the acoustic surveys has been to estimate the relative biomass of the adult spawning stock by year. A secondary objective has been to provide biomass estimates of pre-recruit fish and therefore the survey transects extend into 300 m where the younger fish live.

Southern blue whiting acoustic marks were identified as one of three categories of fish; juvenile, immature, or adult. The categories were broadly defined as adult (also known as mature) that consisted mainly of adult fish, which were going to spawn that year; immature that consisted mainly of two-year-olds; and juvenile that consisted mainly of one-year-olds. Identification of each mark to a category was typically made at the time based on the results of research tows, the acoustic 'shape' of the mark, and its depth and location.

We used the survey estimates of immature and mature southern blue whiting, and assumed that these were relative estimates of mid-season biomass (i.e., after half the catch for that season has been removed), with a CV equal to the sampling CV estimated from the survey. We ignore the juvenile category in the assessment because biomass estimates of the juvenile category (mainly one-year-olds) were generally low and inconsistent with subsequent estimates of those year classes, and so were unlikely to be a good index of abundance (Dunn & Hanchet 2011).

The acoustic biomass observations were fitted using a lognormal likelihood,

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

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

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

Table 2: R.V. *Tangaroa* **juvenile, immature, and mature acoustic biomass estimates (t) and CV for the Campbell Island Rise 1993–2013 using the revised target strength derived by O'Driscoll et al. (2013).**

Year	Juvenile		Immature		Mature		Total	Source
	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	
1993	0	0.00	35 208	0.25	16 060	0.24	51 268	(Fu et al. 2013)
1994	0	0.00	5 523	0.38	72 168	0.34	77 691	(Fu et al. 2013)
1995	0	0.00	15 507	0.29	53 608	0.30	69 114	(Fu et al. 2013)
1998	322	0.45	6 759	0.20	91 639	0.14	98 720	(Fu et al. 2013)
2000	423	0.39	1 864	0.24	71 749	0.17	74 035	(Fu et al. 2013)
2002	1 969	0.39	247	0.76	66 034	0.68	68 250	(Fu et al. 2013)
2004	639	0.67	5 617	0.16	42 236	0.35	48 492	(Fu et al. 2013)
2006	504	0.38	3 423	0.24	43 843	0.32	47 770	(Fu et al. 2013)
2009	0	–	24 479	0.26	99 521	0.27	124 000	(Fu et al. 2013)
2011	0	–	14 454	0.17	53 299	0.22	67 753	(Fu et al. 2013)
2013	0	–	8 004	0.55	65 801	0.25	73 805	(O'Driscoll et al. 2014)

2.2.2 Proportions-at-age in the commercial catch

Catch-at-age observations by sex were available from the commercial fishery for 1979 to 2015 from observer data, excluding 1987 (Figure 3). While length data were available for 1987, there were no otoliths aged from 1987, so the age length key was estimated using the length at age keys from 1986 and 1988, and adding or subtracting 1 year's growth respectively, following Hanchet & Ingerson (1995). 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,

$$-\log(L) = -\log(N!) + \sum_{i} \left[\log((NO_i)!) - NO_i \log(E_i) \right]$$

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. Dunn & Hanchet (2016) described the catch-at-age data available for the assessment models from 1990, and data before 1990 was described by Hanchet et al. (2006). The derivation of the assumed multinomial sample sizes for the proportions-at-age data is described below.
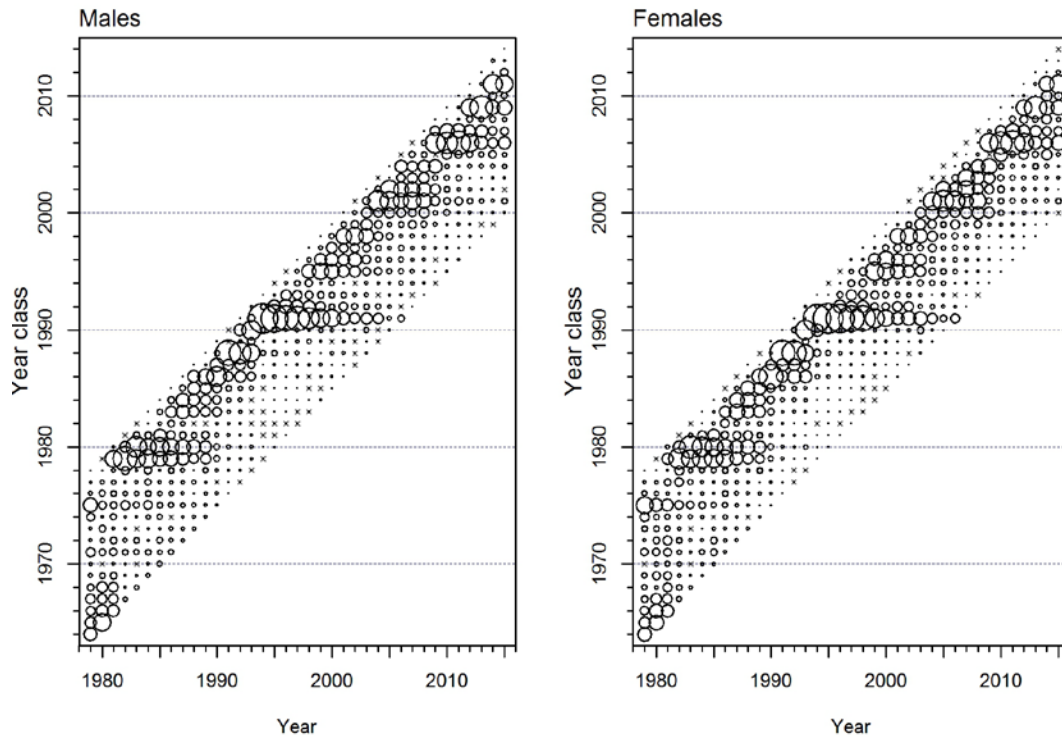
Figure 3: Commercial catch proportions at age for the Campbell Island stock by sex and year class, 1978–2015 for ages 2–15+. Symbol area proportional to the proportions-at-age within the sampling event.

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

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

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) by inspecting the 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 Markov Chain Monte Carlo (MCMC). The Metropolis algorithm draws 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(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 initially estimated using single chains, with a burn-in length of 1×10^6 iterations, with every 10 000th sample taken from the next 1×10^7 iterations (i.e., a systematic sample of length 1000 was taken from the Bayesian posterior).

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 3). The exceptions to this were the priors and penalties on acoustic biomass catchability coefficients for mature fish, relative year class strengths and natural mortality (sensitivity runs only). The prior assumed for the relative year class strengths was lognormal, with mean 1.0 and CV 1.3, for all year classes.

Table 3: The parameters, number of degrees of freedom (N), selectivity shape (shape), priors (including distributions, and means and CVs for the lognormal), and bounds assumed for estimated parameters for the models. *Note that natural mortality was only estimated in one of the sensitivity runs.

Parameter	N	Distribution	Mean	CV	Lower	Upper
B_0	1	Uniform-log	–	–	30 000	800 000
Initial population (by sex)	14	Uniform	–	–	2e2	2e9
Male maturation ogive	5	Uniform	–	–	0.001	0.999
Female fishing selectivity	5	Uniform	–	–	0.001	0.999
Year class strength	36	Lognormal	1.0	1.3	0.001	100
Acoustic catchability q						
Mature	1	Lognormal	0.54	0.44	0.1	1.71
Immature	1	Uniform	–	–	0.1	1.71
*Natural mortality (average)	1	lognormal	0.2	0.2	0.075	0.325
*Natural mortality (difference)	1	Normal	0.0	0.05	-0.05	0.05

A new log-normal prior was developed for the wide area acoustic survey catchability coefficient obtained using the approach of Cordue (1996). The main difference between the revised prior and the original prior used in the 2013 assessment (Dunn & Hanchet 2015) was the inclusion of uncertainty over the tilt angle of southern blue whiting. Individual priors were developed for the key factors, including target strength, acoustic system calibration, target identification, shadow or dead zone correction, and spatial availability and these were then aggregated to develop an overall lognormal prior which had a mean of 0.54 and CV of 0.44 (Table 4).

Table 4: Original and revised 'best' and lower and upper bounds for the factors for the acoustic catchability prior. A lognormal prior with mean 0.54 and CV 0.44 was used for the assessment.

Factor	Original			Revised		
	Lower	Best	Upper	Lower	Best	Upper
Target strength: Uncertainty	0.72	0.90	1.13	0.80	1.00	1.20
Target strength: Tilt angle	-	-	-	0.25	0.70	1.00
Target identification	0.90	1.15	1.45	0.85	1.00	1.15
Vertical availability	0.75	0.85	0.95	0.90	0.95	1.00
Areal availability	0.90	0.95	1.00	0.80	0.90	1.00
System calibration	0.90	1.00	1.10	0.90	1.00	1.10
Combined	0.39	0.84	1.71	0.11	0.60	1.52
Lognormal parameters	mu=0.87, CV=0.30			mu=0.54, CV=0.44		

Natural mortality was estimated to be 0.2 y^{-1} by Hanchet (1991). When estimated, natural mortality was parameterised by the average of male and female, with the difference estimated with an associated normal prior with a mean of zero and bounds of 0.05 y^{-1}. The prior on the average natural mortality was assumed to be a normal distribution with mean of 0.2 y^{-1} and CV 0.2 following Dunn & Hanchet (2015).

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 have mean equal to one.

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 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 obtained by adding additional process error, N_{PE}, to this sample size estimate using Method TA1.8 in Francis (2011) — i.e., from an initial MPD model fit, an estimate of the additional process error was made such that the standardised residuals from the mean observed age and mean expected age in each year had mean equal to one.

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 process error for the acoustic biomass estimates was zero.

2.3.3 Model runs

We considered four model runs: a base case and three sensitivity tests (Table 5). The base case was essentially an update of the previous base case assessment from Dunn & Hanchet (2015), which assumed natural mortality equal to 0.2. Three sensitivity tests were carried out, which all considered the influence of uncertainty in natural mortality in the model: the first two assumed natural mortality equal to 0.15 or 0.25; and the third allowed for the estimation of the natural mortality rate for males and females.

Table 5: Model run labels and descriptions for the model runs.

Model type	Model label	Description
Base case	1.1	Base case model with natural mortality equal to 0.2
Sensitivity	2.1	Model 1.1, but with natural mortality equal to 0.15
Sensitivity	2.2	Model 1.1, but with natural mortality equal to 0.25
Sensitivity	1.3	Model 1.1, but with natural mortality estimated

3. RESULTS

3.1 MPD results

The spawning stock biomass trajectories for the MPD fits are shown for the base case (model 1.1) in Figure 4. The relative year class strengths, and fits to the acoustic indices and mean age are also shown in Figure 4. Fits to the mean age and acoustic indices were generally good, but the model was unable to fit the very high mature and immature biomass seen in the 2009 acoustic survey.

The fits to the mature biomass acoustic indices and the age data looked very similar for the three sensitivity runs (not shown). *M* was estimated to be 0.17 in model run 1.3.
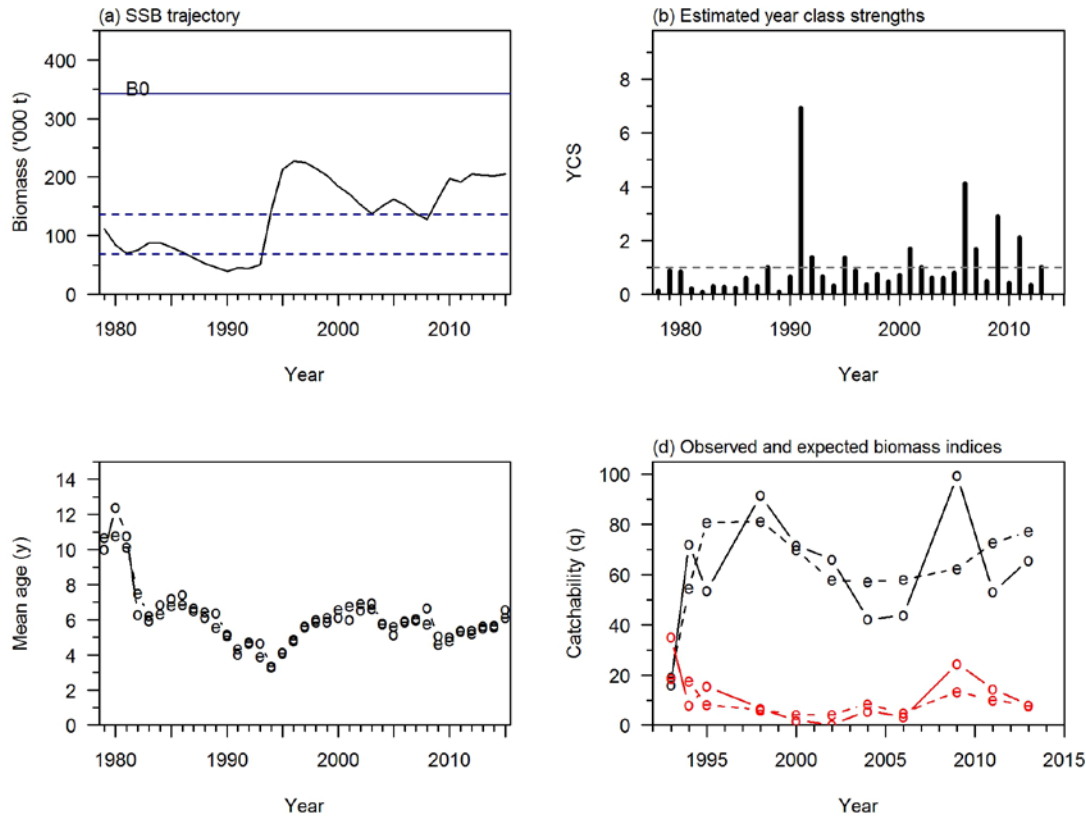
Figure 4: Results of MPD fits for model run 1.1 showing (a) estimated SSB trajectory (with 40% B_0 shown as a dashed line) 1979–2015; (b) estimated relative year class strength (with the average of one shown as a dashed line); (c) observed (o) and expected (e) mean age fits for the commercial catch-at-age data; and (d) observed (o) and expected (e) mature (black) and immature (red) acoustic biomass indices.

3.2 MCMC results

3.2.1 MCMC diagnostics

MCMC traces were reasonably good for B_0 and for B_{2015} (%B_0) for the base case model (Figure 5) and for the sensitivity model runs 2.1 and 2.2 (not shown). Plots of relative jump size and autocorrelation were generally good, although the age 9 initial population ($C_{initial}$) parameter performed poorly and may be poorly estimated by these models.

In contrast, MCMC traces showed signs of non-convergence for sensitivity model run 1.3 and there was evidence of autocorrelation in estimates of B_0, which suggests that this run should be rejected (Figure 6).
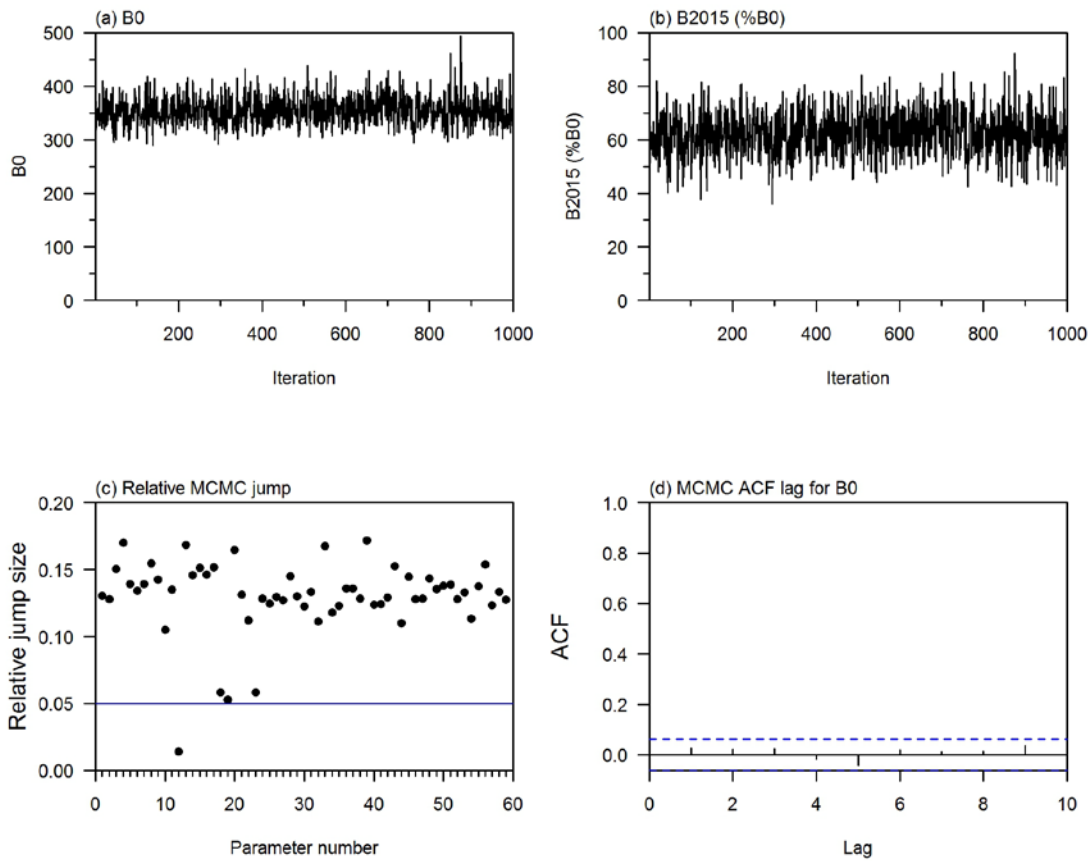
Figure 5: MCMC posterior trace plots for the base case, where (a) B_0, (b) current status (%B_{2015}/B_0), (c) median relative jump size for all parameters (x-axis, labelled 1–60 where the line indicates a threshold test for non-convergence – age 9 initial population ($C_{initial}$) was the only parameter falling below this threshold), and (d) autocorrelation lag plot for B_0 (where the dashed line indicates an autocorrelation that is higher than 0.05).
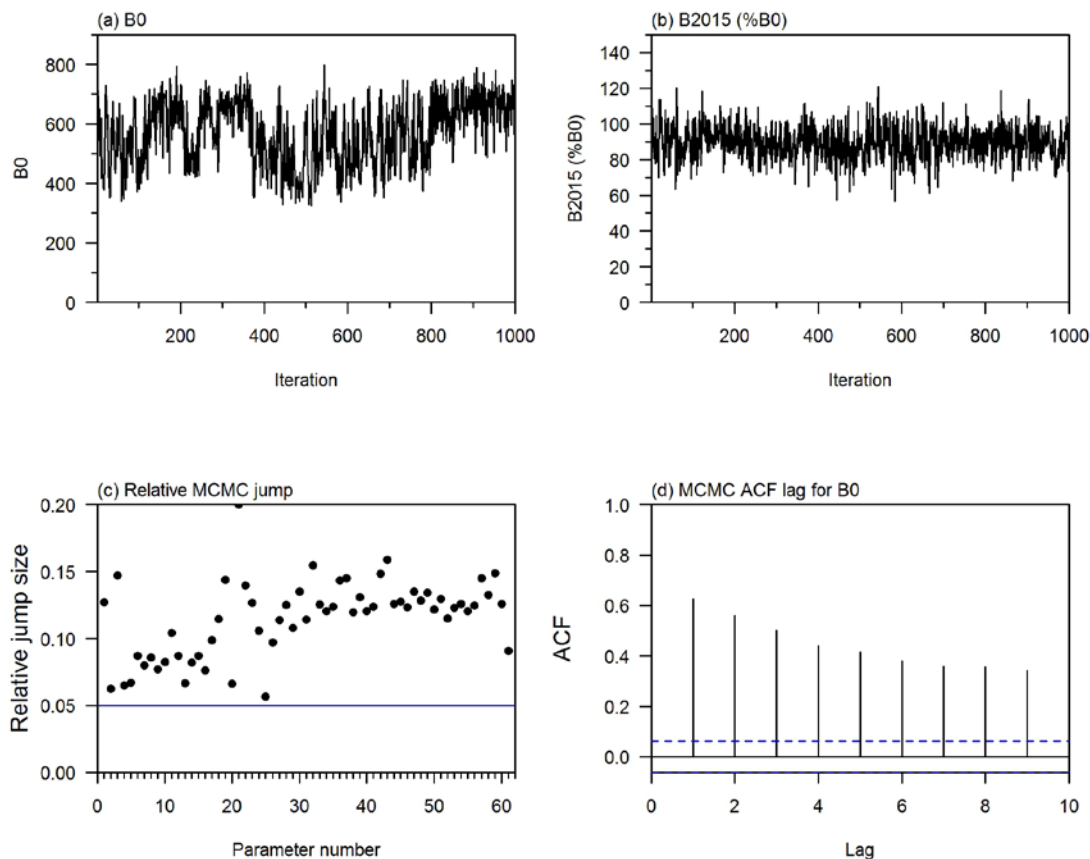
Figure 6: MCMC posterior trace plots for sensitivity run 1.3, where (a) B_0, (b) current status (%B_{2015}/B_0), (c) median relative jump size for all parameters (x-axis, labelled 1–60 where the line indicates a threshold test for non-convergence), and (d) autocorrelation lag plot for B_0 (where the dashed line indicates an autocorrelation that is higher than 0.05).

3.2.2 MCMC estimates

Base case model run

The estimated MCMC marginal posterior distributions for parameters of interest are shown for the base case (model run 1.1) in Figure 7 and Figure 8, and the results summarised in Table 6 and Table 7. This run suggested that the spawning stock biomass steadily declined from the early 1980s until 1993, followed by a large increase to 1995 resulting from the recruitment of the strong 1991 year class. The spawning population then declined steadily from 1997 until 2008, and then showed a moderate increase to 2015 as the 2006 and 2009 and then 2011 year classes recruited to the fishery. At the start of the model run in 1979, the spawning stock biomass was estimated to be at about 45% B_0. During the late 1980s and early 1990s the biomass was estimated to have dropped below 20% B_0 for several years but then to have increased to about 60% B_0 when the strong 1991 year class entered the fishery. Since then the spawning stock biomass is estimated to have been above 40% B_0.

Year class strength has been highly variable over the course of the fishery. The 1991 year class was about six times stronger than any other year classes until at least 2006, and gave rise to the large increase in biomass seen during the mid-1990s. There were several above average year classes during the mid to late 1990s and in early 2000, but these contributed to only a small proportion of the catch and have probably been largely removed from the population. The size of the 2006 and 2009 year

classes was estimated to be at about 3–4 times the average, with large numbers of the 2006 and 2009 year class caught in the fishery and large numbers of both year classes observed by the 2009, 2011, and 2013 acoustic surveys.

The estimate of the median mature biomass acoustic q was 0.36, which is less than the prior value of 0.54. This would suggest that the acoustic surveys are underestimating the adult biomass, or that the prior itself was poorly estimated. The estimate of the median immature biomass acoustic q was 0.28, which is less than the estimate for the median mature biomass.

Table 6: Bayesian median and 95% credible intervals of equilibrium (B_0), current spawning stock biomass, and current status (%B_0)for model run 1.1 (base case), and the sensitivity cases.

Model	B_0	B_{2015}	B_{2015} (%B_0)
Base case	352 200 (307 200–412 500)	220 200 (141 700–323 400)	62 (46–79)
2.1	394 100 (354 900–447 900)	175 400 (113 100–261 900)	44 (32–58)
2.2	375 800 (312 800–474 200)	293 000 (192 000–450 200)	78 (60–97)
1.3	638 400 (387 100–792 800)	575 000 (295 600–805 400)	90 (72–109)

Table 7: Bayesian median and 95% credible intervals of the catchability coefficients (q) for the wide area acoustic biomass indices and estimates of natural mortality for model runs 1.1 (base case) and the sensitivity cases.

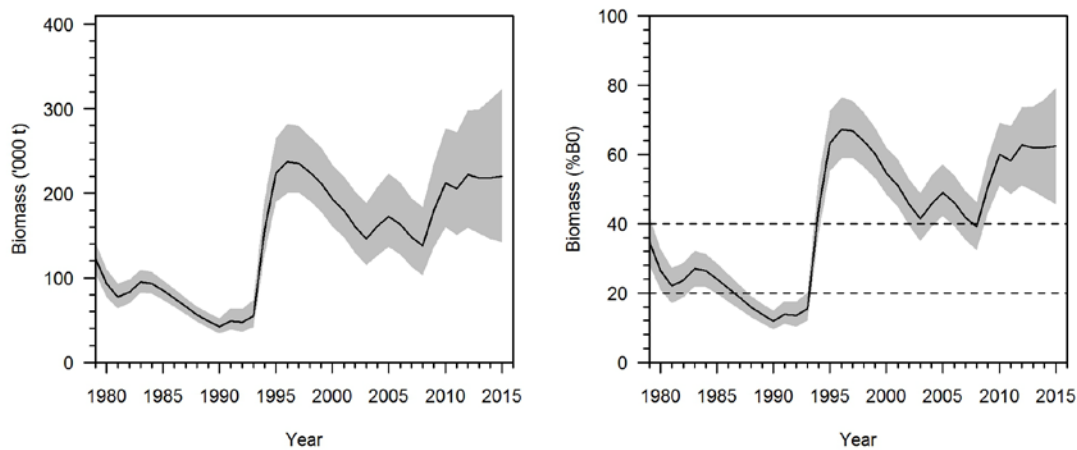| Model	Catchability		Natural mortality	
	Mature	Immature	Male	Female
Base case	0.36 (0.29–0.43)	0.28 (0.23–0.33)	–	–
2.1	0.47 (0.40–0.54)	0.40 (0.34–0.49)	–	--
2.2	0.25 (0.19–0.32)	0.18 (0.14–0.22)	–	--
1.3	0.11 (0.08–0.21)	0.06 (0.04–0.14)	0.34 (0.27–0.40)	0.32 (0.25–0.38)

Figure 7: MCMC median and 95% credible intervals of the trajectory of (left) spawning stock biomass and (right) stock status (%B_0) for the base case.
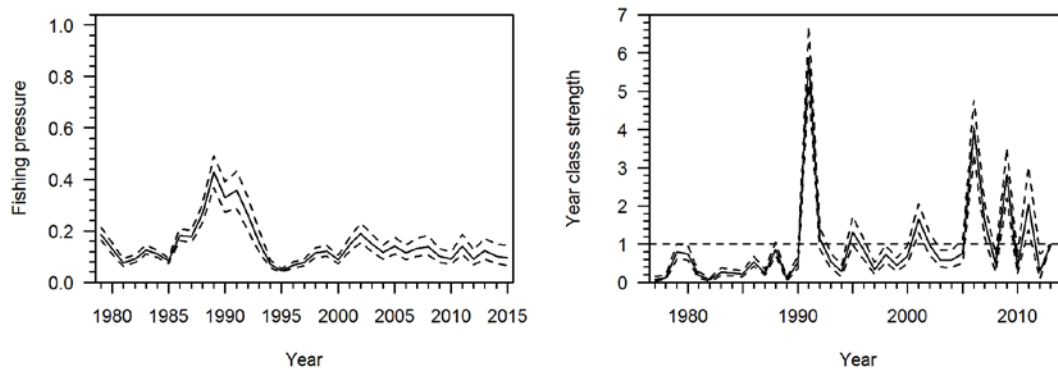
Figure 8: MCMC median and 95% credible intervals for (left) exploitation rates and (right) relative year class strength for the base case.

Model sensitivity runs

The estimated MCMC marginal posterior distributions for parameters of interest are shown for the sensitivity model runs in Figures 9–11, and the results summarised in Tables 6 and 7.

The biomass trajectories for all three sensitivity runs showed very similar patterns to the base case. However, the key difference was in the level of biomass and stock status. As would be expected, the estimate of B_0, current biomass and current status was lower for model run 2.1 but higher for model runs 2.2 and 1.3. Although the current status for model run 2.1 was more pessimistic than the base case, the median was still above 40% B_0. In contrast, the current status for model run 1.3 was much more optimistic at 90% B_0. However, natural mortality was estimated to be 0.34 y^{-1} for males and 0.32 y^{-1} for females, which is implausible.
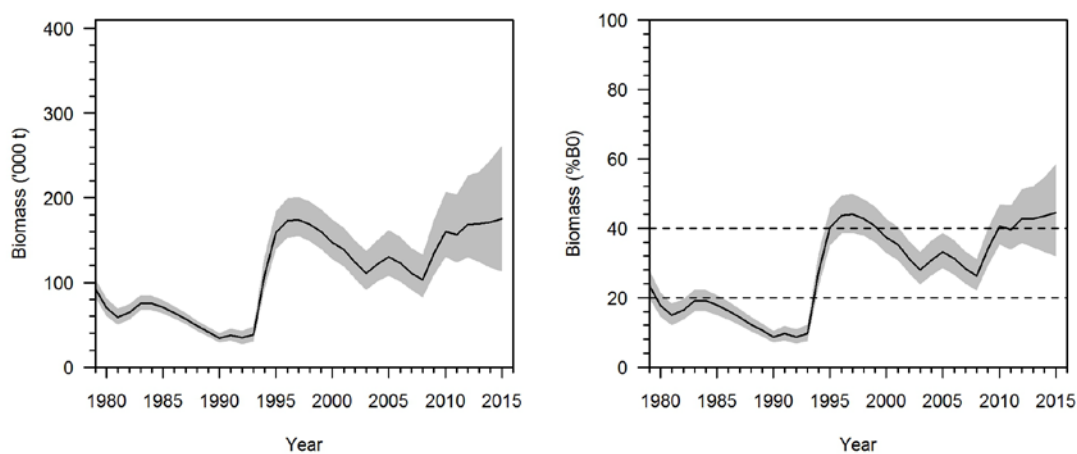

Figure 9: MCMC median and 95% credible intervals of the trajectory of (left) spawning stock biomass and (right) stock status (%B_0) for run 2.1.
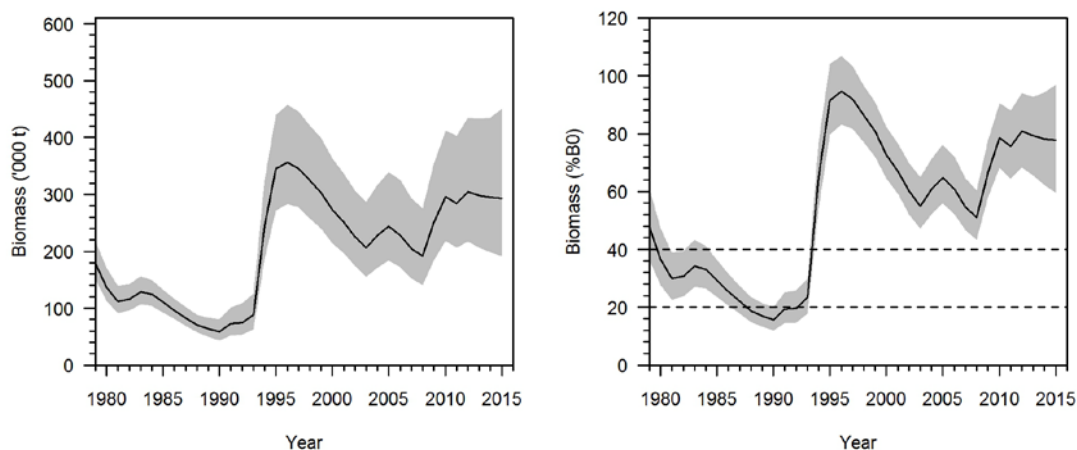
Figure 10: MCMC median and 95% credible intervals of the trajectory of (left) spawning stock biomass and (right) stock status (%B_0) for run 2.2.
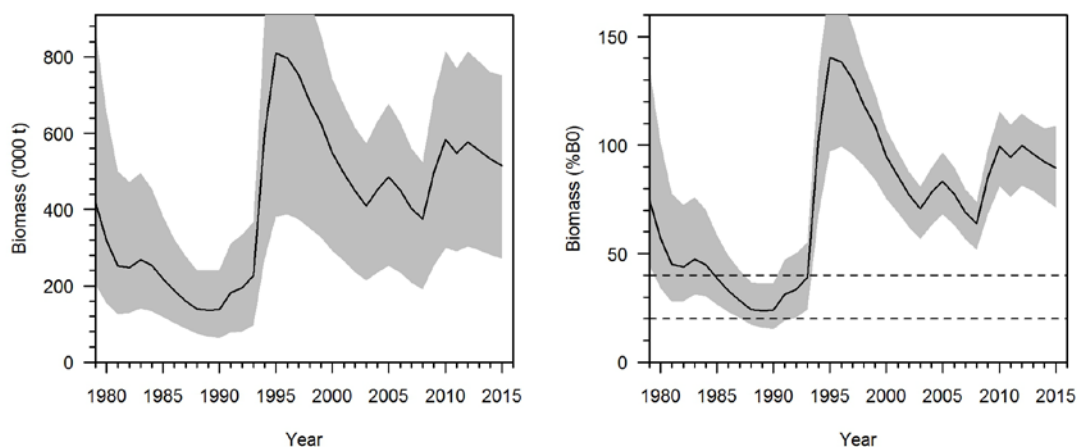

Figure 11: MCMC median and 95% credible intervals of the trajectory of (left) spawning stock biomass and (right) stock status (%B_0) for run 1.3.

3.3 Projections

Projections were made for the base case model and the two plausible sensitivity model runs 2.1 and 2.2 assuming fixed catch levels of 23 000 t and 40 000 t. Projections were made using the MCMC samples, with recruitments drawn randomly from the distribution of year class strengths for the period 1977–2012 estimated by the model and applied from year 2013 onwards (Figures 12 to 14). Because of the link between mean size at age of fish in the population and the population density, projections assumed that the mean size at age would remain at 2015 estimates, rather than return to the average size at age that might be expected at lower abundances.
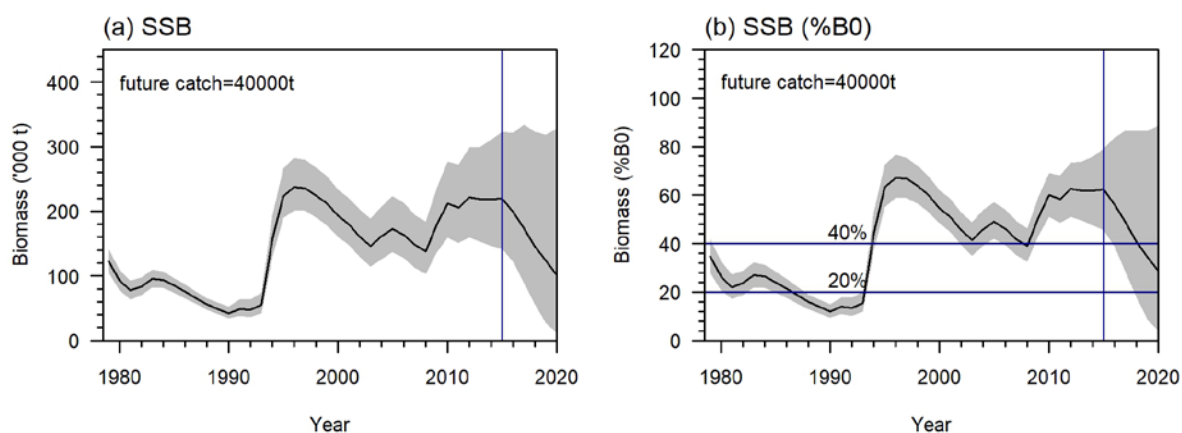
Figure 12: MCMC posterior plots for the median (solid line) and 95% credible intervals for (a) spawning stock biomass and (b) stock status (%B_0) for a catch of 40 000 t for the base case assuming average recruitment. Horizontal lines indicate 40% and 20% B_0, and the vertical line represents the beginning of the projection period (2016–2020).
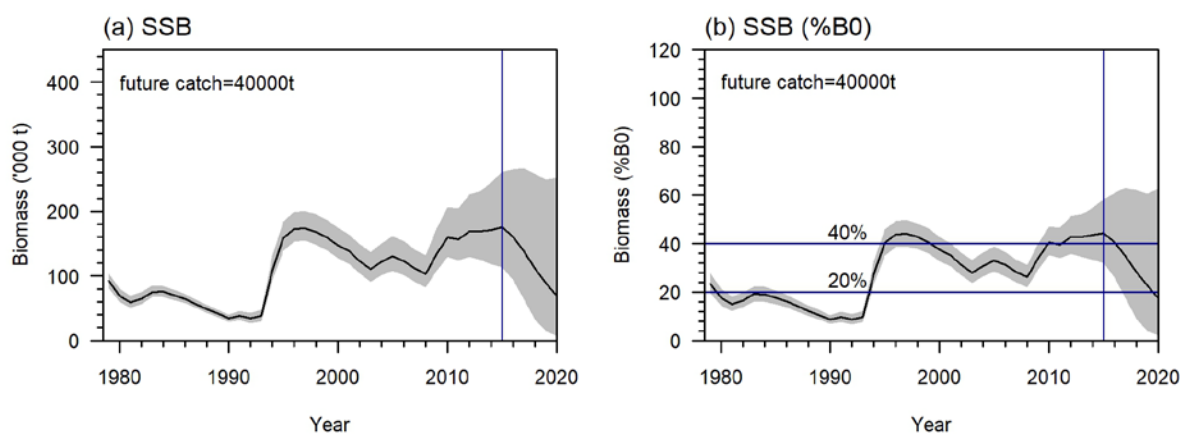

Figure 13: MCMC posterior plots for the median (solid line) and 95% credible intervals for (a) spawning stock biomass and (b) stock status (%B_0) for a catch of 40 000 t for model run 2.1 assuming average recruitment. Horizontal lines indicate 40% and 20% B_0, and the vertical line represents the beginning of the projection period (2016–2020).
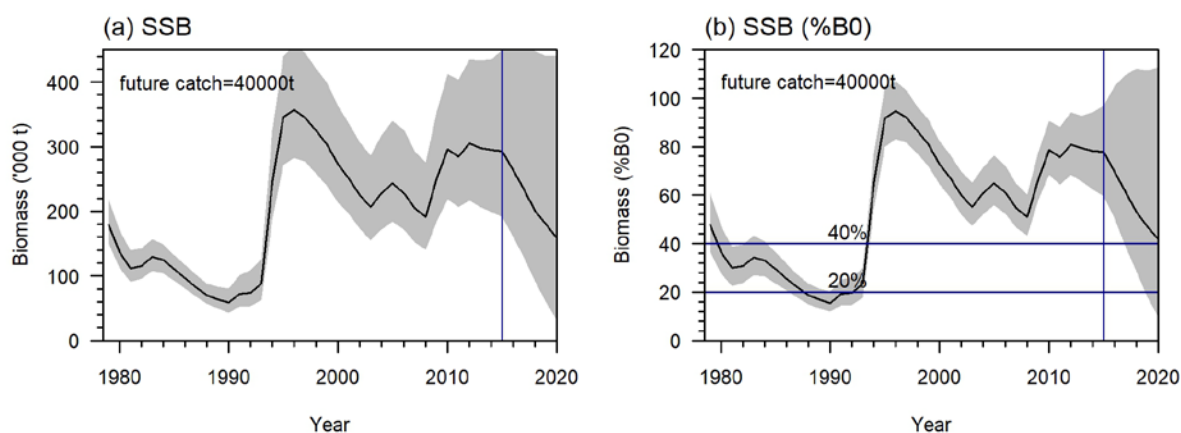
Figure 14: MCMC posterior plots for the median (solid line) and 95% credible intervals for (a) spawning stock biomass and (b) stock status (%B_0) for a catch of 40 000 t for model run 2.2 assuming average recruitment. Horizontal lines indicate 40% and 20% B_0, and the vertical line represents the beginning of the projection period (2016–2020).

For each scenario, the probability that the mid-season biomass for the specified year will be less than the threshold level (20% B_0) is given in Table 8. The probability of dropping below the threshold biomass at catch levels of 23 000 t was less than 10% for all models and all years. The probability of dropping below the threshold biomass at catch levels of 40 000 t exceeded 10% by 2019 for the base case. Under average recruitment conditions the biomass was expected to steadily decline under both catch scenarios in all three model runs.

Table 8: Probability that the projected mid-season spawning stock biomass for 2016–2020 will be less than 20% B_0 at a projected catch of 23 000 t and 40 000 t, for model run 1.1 (M=0.20 y^{-1}), 2.1 (M=0.15 y^{-1}), and 2.2 (M=0.25 y^{-1}) assuming average recruitment over the period 1977–2012 for 2013+.

Model	Catch	$Pr(B < 0.2B_0)$				
	(t)	2016	2017	2018	2019	2020
1.1	23 000	0.00	0.00	0.00	0.01	0.03
	40 000	0.00	0.00	0.04	0.16	0.31
2.1	23 000	0.00	0.00	0.02	0.06	0.11
	40 000	0.00	0.05	0.23	0.42	0.58
2.2	23 000	0.00	0.00	0.00	0.00	0.01
	40 000	0.00	0.00	0.01	0.04	0.11

4. DISCUSSION

The results of the base case assessment suggested that the spawning stock biomass of the Campbell Island Rise in 2015 was 220 200 t (95% C.I.s 141 700–323 400 t) and was 62% B_0 (95% C.I.s 46–79%). Projections with an annual catch of 40 000 t suggested that the spawning stock biomass was expected to decline steadily over the following five year period. There was little difference in the biomass trend between the base case and the two sensitivity model runs used for the projections, although model run 2.1 (low M) was less optimistic in the current status and projected status and model run 2.2 (high M) was more optimistic.

An additional sensitivity run (model run 1.3) was carried out where natural mortality was estimated in the model. This run estimated M to be 0.32 for females and 0.34 for males, which was inconsistent

with the relatively high proportions of older age fish which have been observed at times in the commercial catch. The high biomass levels (and associated low exploitation rates) for the early 1990s estimated by this model run were also considered to be inconsistent with the very high levels of fishing effort and associated low catches in those years. For example, the model estimated an exploitation rate of only 0.1 in 1992, but in that year the fishing fleet had considerable problems finding and catching southern blue whiting in the Campbell fishery (Hanchet 1993). In fact, in that year a total of 47 vessels made 1530 tows and caught only 14 000 t in the Campbell fishery, whilst a similar number of vessels caught almost 60 000 t in the Bounty fishery (Dunn & Hanchet 2016).

The assessment was strongly influenced by the high biomass estimates from the last three acoustic surveys. These surveys observed some of the highest estimates of adult and immature biomass since the survey series began in 1993. There is no reason to doubt that the 2006, 2009, and 2011 year classes are strong, but the size of the 2011 year classes is still not well-estimated. The relative strength of these year classes was virtually identical between the models with the 2006 year class being stronger than the 2009 year class followed by the 2011 year class.

The last assessment of the Campbell Island Rise stock was carried out in 2013 (Dunn & Hanchet 2015). Estimates of B_{1979} and the stock trajectory up to 2013 were similar to the previous assessment, but the current model results had several slight differences: (i) a slightly lower spawning biomass in 2013, (ii) a slightly higher B_0, and (iii) a higher estimate of the 2011 year class. As discussed above, the main driver for the slight decrease in spawning biomass was the lower estimates of adult biomass in the 2011 and 2013 acoustic surveys compared to the 2009 survey. A new survey was conducted in September 2016, and this should give a better idea of the biomass of older fish, as well as the relative strength of the recent year classes.

The other important difference between previous assessments and this one was the estimate of B_0, which has been poorly estimated in southern blue whiting models as a consequence of a few very strong year classes strongly influencing estimates of average recruitment. In recent years, the influx of several new and strong year classes has also impacted the estimate of average recruitment, and hence has resulted in changing estimates of B_0. In earlier assessments, B_0 was estimated to be lower – for example in 2006 it was estimated to be 245 000 t (Hanchet et al. 2006). With the recent occurrence of several strong year classes in the fishery, the estimate of B_0 increased to 343 000 t in the 2013 assessment (Dunn & Hanchet 2015) and again to 352 000 t in the current assessment.

The estimate of the median mature biomass acoustic q was 0.36 for the base case. This estimate was substantially lower than the mean of the prior of 0.54. This suggests that either the acoustic surveys were underestimating the adult biomass, or that the acoustic adult biomass prior may not have been well-specified (were biased). The main uncertainty in the estimate of the prior is the assumption of the target strength-fish length relationship. We note that further work is underway to determine the average tilt angle of southern blue whiting *in situ*, so that this prior can be more accurately and precisely estimated.

5. ACKNOWLEDGEMENTS

6. REFERENCES

Bull, B.; Dunn, A. (2002). Catch-at-age: User manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. National Institute of Water and Atmospheric Research. (Unpublished report held in NIWA library, Wellington.)

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. *NIWA Technical Report. 135.* 280 p.

Cordue, P.L. (1996). A model-based method for bounding virgin biomass using a catch history, relative biomass indices, and ancillary information. New Zealand Fisheries Assessment Research Document 96/8. 48 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Dunn, A.; Hanchet, S.M. (2011). Southern blue whiting (*Micromesistius australis*) stock assessment for the Campbell Island Rise, 2009–10. *New Zealand Fisheries Assessment Report 2011/40.* 37 p.

Dunn, A.; Hanchet, S.M. (2015). Southern blue whiting (*Micromesistius australis*) stock assessment for the Campbell Island Rise for 2013 with revised target strength acoustic biomass estimates. *New Zealand Fisheries Assessment Report 2015/80.* 23 p.

Dunn, A.; Hanchet, S.M. (2016). Review and summary of the time series of input data available for the assessment of southern blue whiting (*Micromesistius australis*) stocks up to and including the 2015 season. *New Zealand Fisheries Assessment Report 2016/43.* 43 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68:* 1124–1138.

Fu, D.; Hanchet, S.M.; O'Driscoll, R.L. (2013). Estimates of biomass and c.v.s of southern blue whiting from previous acoustic surveys from 1993 to 2012 using a new target strength – fish length relationship. Final Research Report to the Ministry of Fisheries. Project DEE201002SBWB. 52 p. National Institute of Water and Atmospheric Research. (Unpublished report held by the Ministry for Primary Industries.)

Gelman, A.B.; Carlin, J.S.; Stern, H.S.; Rubin, D.B. (1995). Bayesian data analysis. Chapman and Hall, London. 526 p.

Gilks, W.R.; Richardson, S.; Spiegelhalter, D.J. (eds.) (1998). Markov chain Monte Carlo in practice. *Interdisciplinary statistics.* 399 p. Chapman and Hall/CRC Press, Boca Raton, Florida.

Hanchet, S.M. (1991). Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1991–92 fishing year. New Zealand Fisheries Assessment Research Document 91/7. 32 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Hanchet, S.M. (1993). Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1993–94 fishing year. New Zealand Fisheries Assessment Research Document 93/17. 56 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Hanchet, S.M.; Blackwell, R.G.; Stevenson, M.L. (2006). Southern blue whiting (*Micromesistius australis*) stock assessment for the Campbell Island Rise for 2006. *New Zealand Fisheries Assessment Report 2006/41.* 45 p.

Hanchet, S.M.; Haist, V.; Fournier, D. (1998). An integrated assessment of southern blue whiting (*Micromesistius australis*) from New Zealand waters using separable Sequential Population Analysis. *In:* Fishery Stock Assessment Models. Funk, F.; Quinn II, T.J.; Heifetz, J.; Ianelli, J.N.; Powers, J.E.; Schweigert, J.F.; Sullivan, P.J.; Zhang, C.-I. (eds.). University of Alaska Sea Grant AK-SG-98-01, Fairbanks, Alaska.

Hanchet, S.M.; Ingerson, J.K.V. (1995). Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1995–96 fishing year. New Zealand Fisheries Assessment Research Document 95/20. 37 p. Ministry of Fisheries.

O'Driscoll, R.L.; Dunford, A.J.; Ladroit, Y. (2014). Acoustic estimates of southern blue whiting from the Campbell Island Rise, August-September 2013. *New Zealand Fisheries Assessment Report 2014/22.* 46 p.

O'Driscoll, R.L.; Oeffner, J.; Dunford, A.J. (2013). In situ target strength estimates of optically verified southern blue whiting (*Micromesistius australis*). *ICES Journal of Marine Science 70:* 431–439.