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Manatū Ahu Matua

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

A. Dunn,
S.M. Hanchet

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Growing and Protecting New Zealand

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EXECUTIVE SUMMARY

This report documents the development of a stock assessment for the Campbell Island Rise stock of southern blue whiting for 1979–2013 using catch history, proportion-at-age, and acoustic survey data up to and including the 2013 season. The primary data sources on abundance were the *R.V. Tangaroa* wide area acoustic surveys carried out from 1993 to 2013 and proportion-at-age data from 1979 to 2013.

The results of the base case assessment suggested that the biomass of the Campbell Island Rise stock in 2013 was 205 500 t (95% C.I.s 145 900–284 500 t) and was 60% B_0 (95% C.I.s 48–74%). The biomass is expected to increase with an assumption of a constant catch equal to the current TAC in 2014 (30 000 t) and 2015 before declining thereafter. The assessment is strongly influenced by the high recent biomass estimates from the last three acoustic surveys.

These median estimates of B_0 were higher than those from the 2011 assessment and higher than earlier estimates of B_0 from this stock. This is primarily due to the strong 2006, 2007, and 2009 year classes which have entered the fishery. There is little doubt that these year classes are strong, although not as strong as the previous strong 1991 year class, and that the increase observed in recent years is due to these strong year classes.
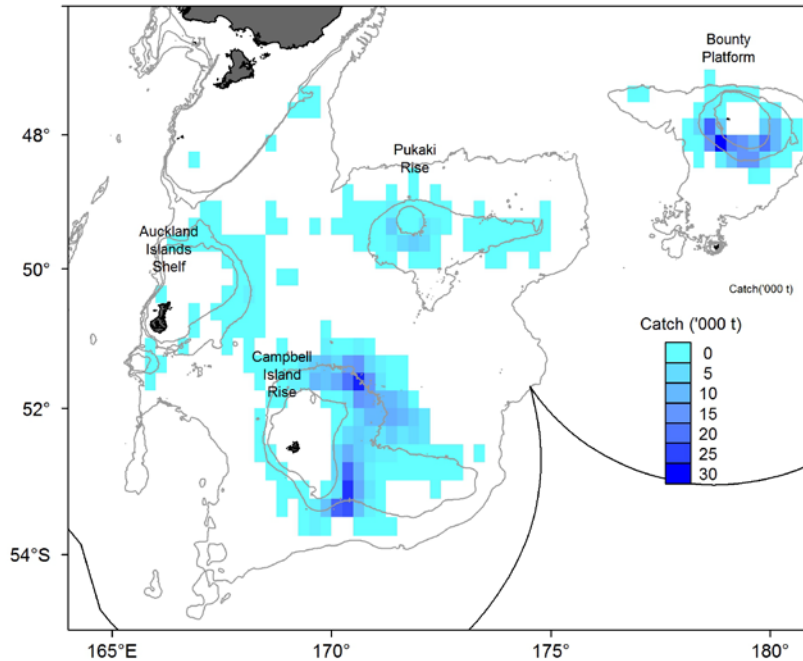
1. INTRODUCTION

Southern blue whiting are almost entirely restricted in distribution to sub-Antarctic waters. They are dispersed throughout the Campbell Plateau and Bounty Platform for much of the year, but during August and September they aggregate to spawn near the Campbell Islands, on Pukaki Rise, on Bounty Platform, and near Auckland Islands over depths of 250–600 m (Figure 1). During most years fish in the spawning fishery range between 35–50 cm fork length (FL), although occasionally smaller length classes of males (29–32 cm FL) have been observed in the catch (Dunn & Hanchet 2015).

Commercial fishing has been concentrated on the Campbell Island Rise and, to a lesser extent, the Bounty Platform. The Pukaki Rise and Auckland Islands have been generally smaller fisheries, with much lower annual catches than the Campbell Island Rise and Bounty Platform fisheries (Dunn & Hanchet 2015).

Acoustic surveys of the Campbell Island Rise stock using R.V. *Tangaroa* have been carried out, typically 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 previous assessment completed for the 2011–12 fishing year (Dunn & Hanchet 2011).

This report documents the assessment of the Campbell Island Rise stock using data up to and including the 2013–14 fishing year (2013 season). We update the assessment using the R.V. *Tangaroa* acoustic indices for 1993–2013 and commercial catch proportions-at-age data from the years 1979–2013. The acoustic indices used revised target strength estimates from Fu et al. (2013). A comprehensive summary of available data used for the assessments of southern blue whiting was described by Dunn & Hanchet (2015).

This report is in fulfilment of the Ministry of Fisheries Project DEE201002SBWC (To carry out stock assessments of southern blue whiting (*Micromesistius australis*) including estimating biomass and sustainable yields) Objective 3 (To update the stock assessment of the Campbell Island stock, including estimating biomass and sustainable yields).

Figure 1: Relative total density of the commercial catch of southern blue whiting by location, TCEPR data 1990–2013.

2. METHODS

2.1 Population dynamics

A two-sex, single stock and 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 2011). 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 2013. Five year projections were run for the years 2014–2018. 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 significant differences observed between males and females 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 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. Year class strengths for the years 1977–2010 were parameterised in the model such that the mean for the years 1977–2010 was assumed to equal one.

In general, southern blue whiting on the Campbell Island Rise are assumed to be mature when on the fishing ground, as they are fished during spawning. 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.

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. 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. The 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 (Dunn & Hanchet 2015). 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 2013.

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.
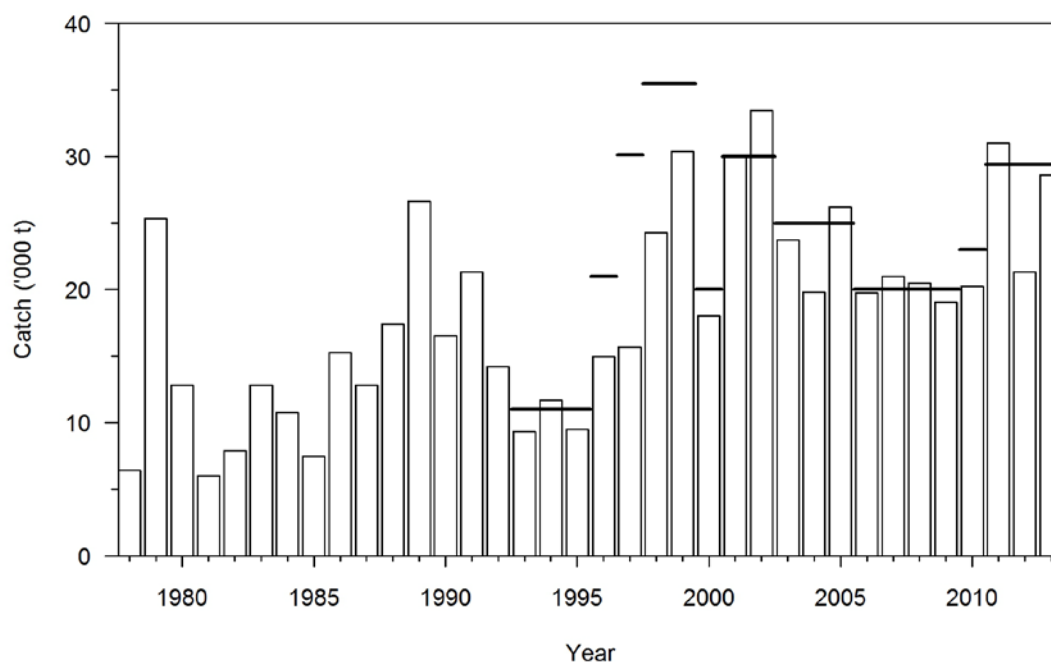
Catches for southern blue whiting have been recorded since 1971 (Dunn & Hanchet 2015), with an average of 25 000 t annual catch between 1971 and 1977 (Figure 2). However, the locations and hence stock associated with the catch in this period is not well known. In addition, age and length sampling of 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 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 Cinitial 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	–	Summer trawl survey
2. Sep–Oct	Age, recruitment, fishing mortality (F), and M	0.1	Growth matrix	Proportions at age Acoustic abundance indices

Figure 2: Reported landings of southern blue whiting on the Campbell Island Rise, 1978–2013. Horizontal lines indicate the TACC since 1993.

2.2 Observations

Available observations for the Campbell Island Rise stock are described in Dunn & Hanchet (2015). They include a time series of catches; wide area acoustic biomass estimates, and associated 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.

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* in the years 1993–1995, 1998, 2000, 2002, 2004, 2006, 2009, 2011, and 2013 (see Dunn & Hanchet 2015 for details). The primary objective of the surveys has been to estimate the biomass of the adult spawning stock. A secondary objective has been to provide estimates of pre-recruit fish and so the surveys extend into shallower water where the younger fish live.

Southern blue whiting acoustic marks were identified as one of three categories of fish; juvenile, immature, and 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 wide area survey acoustic biomass 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,

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

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 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 target strength of O'Driscoll et al. (2013).
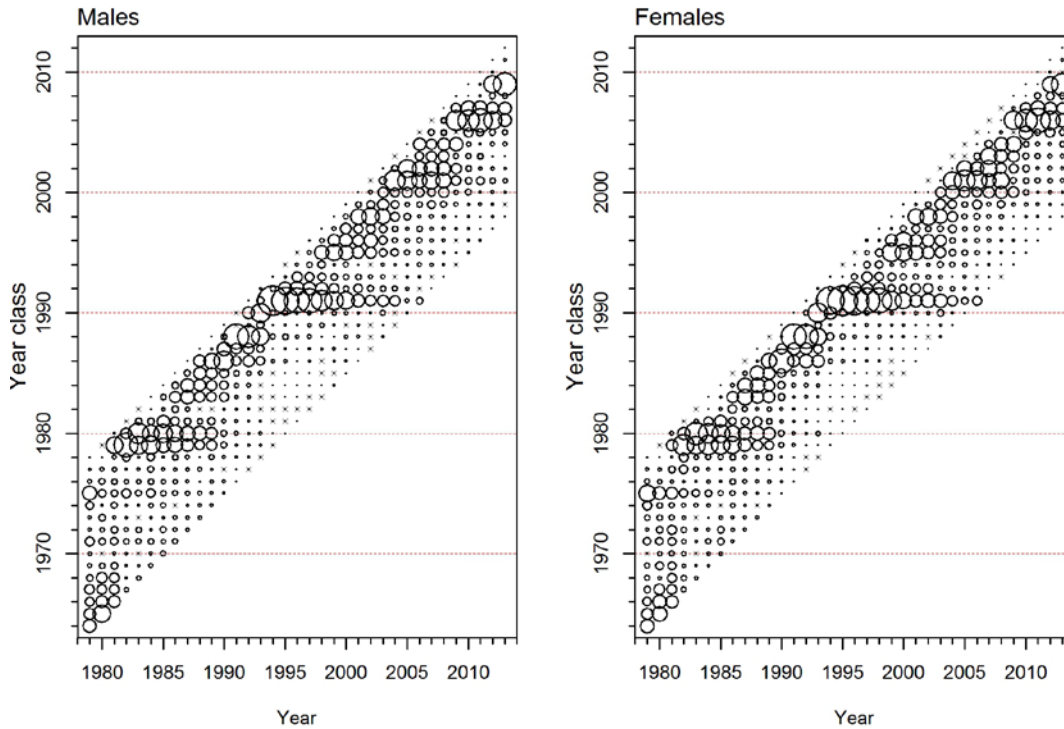
Year	Juvenile		Immature		Mature		Total	Source
	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	
1993	0	–	35 208	0.25	16 060	0.24	51 268	(Fu et al. 2013)
1994	0	–	5 523	0.38	72 168	0.34	77 691	(Fu et al. 2013)
1995	0	–	15 507	0.29	53 608	0.30	69 114	(Fu et al. 2013)
1998	322	0.45	6 759	0.20	91 639	0.14	98 720	(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 2013 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,

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

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. Dunn & Hanchet (2015) 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, 1978–2013 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 $\mathbf{p}$, the vector of the free parameters, L the likelihood function, and O_i the ith observation was

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

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

Initial model fits were evaluated at the maximum of the posterior density (MPD) 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 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., $J(-s)=J(s)$, (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 $10\,000^{th}$ sample taken from the next 1×10^7 iterations (i.e., a systematic sample of length 1000 was taken from the Bayesian posterior). Following presentation in the Deep Water Working Group report, MCMCs were updated using three independent chains. In this report, we present only the results from the three chains.

Single chain diagnostic plots and convergence tests of Geweke (1992) and Heidelberger & Welch (1983) stationarity and half-width were used to determine evidence of non-convergence for single chains. Multi-chain comparisons were made by plotting the posterior distributions of cumulative density and density for B_0 for each of the three independent chains. Where formal tests were used, they 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 3). The exceptions to this were the priors and penalties on acoustic biomass catchability coefficients for mature fish and on the relative year class strengths. 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.

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	34	Lognormal	1.0	1.3	0.001	100
Acoustic catchability q						
Mature	1	Lognormal	0.87	0.3	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 log-normal prior was developed for the wide area acoustic survey catchability coefficient with mean 0.87 and CV 0.3, obtained using the approach of Cordue (1996) and derived for southern blue whiting by P. Cordue (pers. comm., 2013). This was aggregated over various factors including mean target strength, acoustic system calibration, target identification, shadow or dead zone correction, and spatial availability (Table 4). While the analysis indicated a lower bound of 0.39, this did not account for recent updates to

the target strength of southern blue whiting based on *in situ* measurements using an acoustic-optical system (AOS) (O'Driscoll et al. 2013). The AOS target strength estimate was based on observations of fish in the mouth of a trawl, which had a mean swimming angle of 16° and standard deviation of 15°. This may have over-estimated target strength of fish in spawning aggregations, as spawning fish are likely to have a different tilt angle distribution to those being herded by a trawl. Hence, the assessment models assumed a lower bound on the catchability prior of 0.1 to account for this possibility of bias.

Table 4: Estimated 'best' and lower and upper bounds for the factors for the acoustic catchability prior (P. Cordue, pers. comm., 2013). A lognormal prior with mean 0.87 and CV 0.3 was used as this had a median of 0.84 and a 99% range corresponding to the lower and upper estimates.

Factor			Estimate
	Lower	Best	Upper
Target strength	0.72	0.90	1.13
Target identification	0.90	1.15	1.45
Vertical availability	0.75	0.85	0.95
Areal availability	0.90	0.95	1.00
System calibration	0.90	1.00	1.10
Combined	0.39	0.84	1.71

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 mean 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 y^{-1}.

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 a 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 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 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 additional process error for the acoustic biomass estimates was zero.

2.3.3 Model runs

We considered three model runs: a base case and two sensitivity tests (Table 5). The base case included all of the acoustic biomass indices. Two sensitivity tests were carried out; the first excluded the 2009 acoustic biomass index and the second allowed for the estimation of the natural mortality rate for males and females. The first sensitivity test excluded the 2009 acoustic survey index to evaluate the sensitivity of the model to its influence — this value appeared to be significantly higher than neighbouring values and was the highest point observed over the time series. The second sensitivity test considered the influence of uncertainty in natural mortality in the model.

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

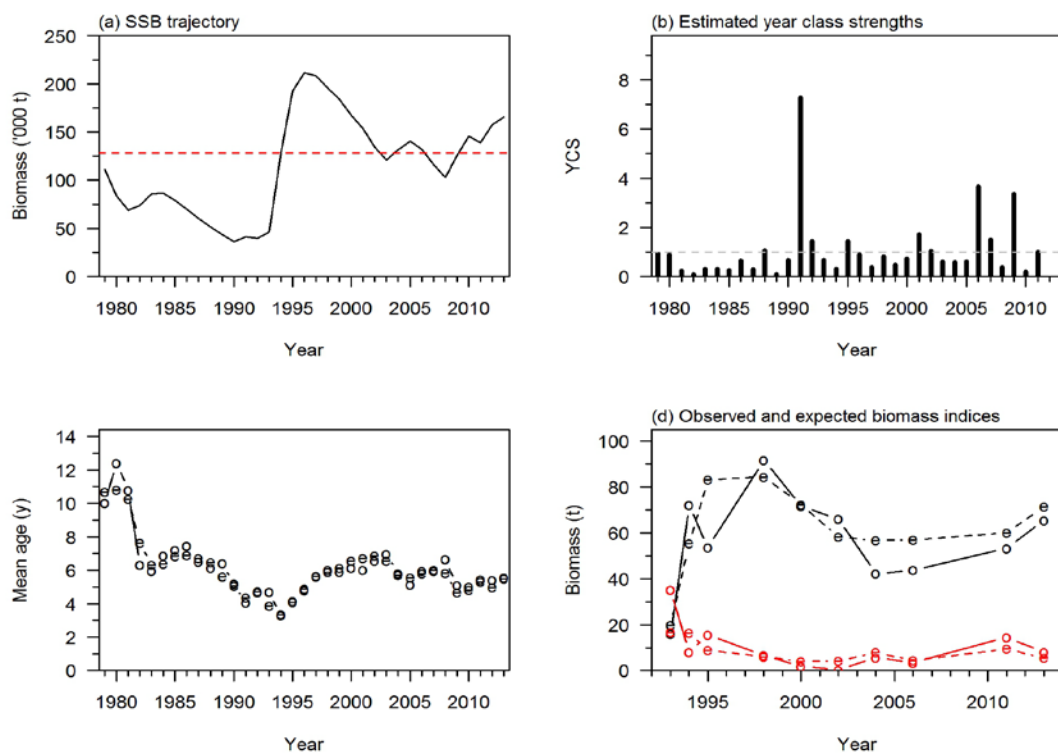| Model type	Model label	Description
Base case	1.1	Base case model
Sensitivity	1.2	Model 1.1, but excluding the 2009 biomass index
Sensitivity	1.3	Model 1.1, but with natural mortality estimated

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 run suggests that the stock biomass showed a steady decline from the early 1980s until 1993, followed by a large increase to 1996 as a result of the strong 1991 year class. The population then declined until a moderate year class in 2001 and then a strong year class in 2006 resulted in a relatively stable stock size until 2009, and then increased in recent years as the 2006 and 2009 year classes recruited to the fishery. 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 are generally good, but the model is unable to fit the very high indices of mature and immature biomass seen in the 2009 acoustic survey.

Similar plots are shown for the two sensitivity model runs in Figure 5 and Figure 6. The fits to the mature acoustic indices for the last two surveys look substantially better for model run 1.2 than the other two runs. The fits to the age data look similar for all runs.
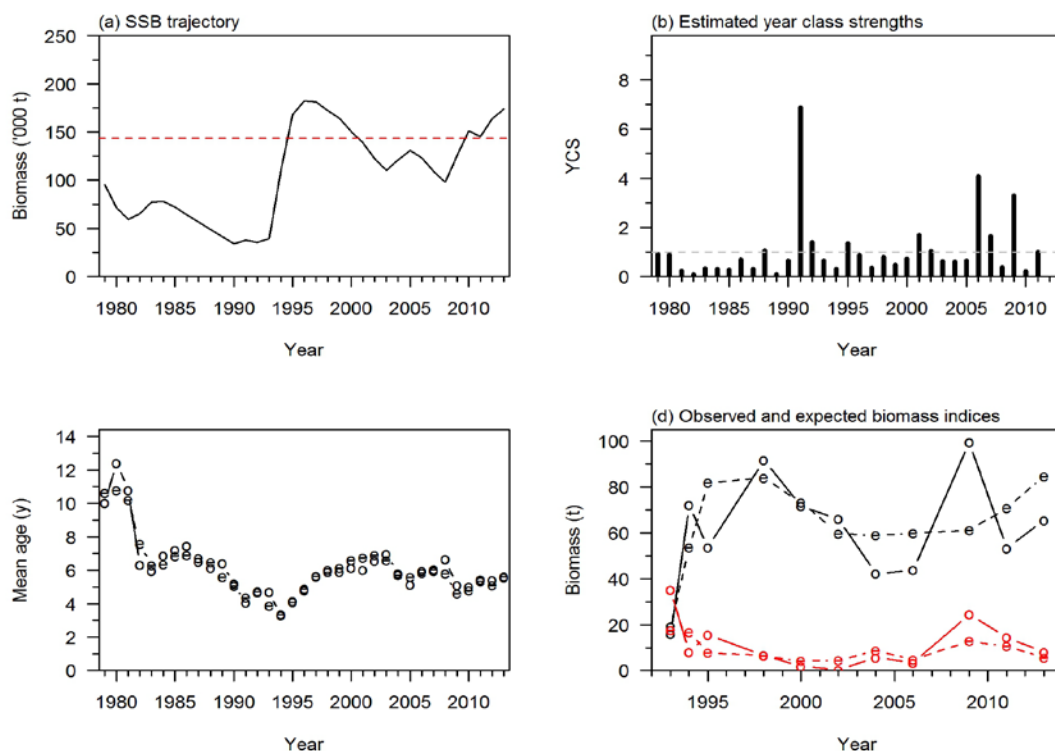

Figure 4: Results of MPD fits for model run 1.1 showing (a) estimated SSB trajectory (with 40% B_0 shown as a dashed line) 1979–2013; (b) estimated relative year class strength (with the average of one shown as a dashed line); (c) observed (o) and expected (e) mean age fits for the commercial catch-at-age data; and (d) observed (o) and expected (e) mature (black) and immature (red) acoustic biomass indices.
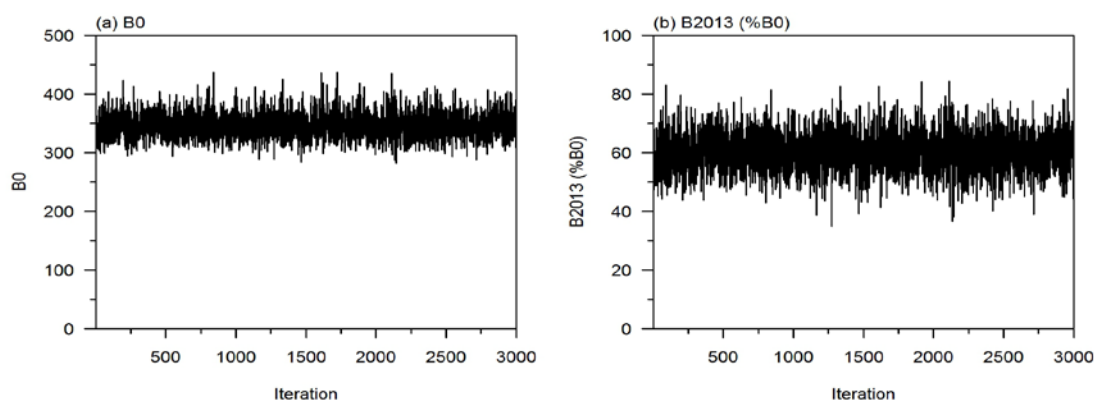
Figure 5: Results of MPD fits for model run 1.2 showing (a) estimated SSB trajectory (with 40% B_0 shown as a dashed line) 1979–2013; (b) estimated relative year class strength (with the average of one shown as a dashed line); (c) observed (o) and expected (e) mean age fits for the commercial catch-at-age data; and (d) observed (o) and expected (e) mature (black) and immature (red) acoustic biomass indices.

Figure 6: Results of MPD fits for model run 1.3 showing (a) estimated SSB trajectory (with 40% B_0 shown as a dashed line) 1979–2013; (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_{2013} (%B_0) for all three model runs 1.1, 1.2, and 1.3 (Figure 7 to Figure 9). MCMC posterior plots of (a) cumulative density and (b) density for B_0 for three independent MCMC chains for the base case (run 1.1), and results of the single chain convergence tests provided no evidence of non-convergence (Figure 10 to Figure 12).

Figure 7: MCMC posterior trace plots for (a) B_0 and (b) current biomass (%B_{2013}/B_0) for the base case (run 1.1).
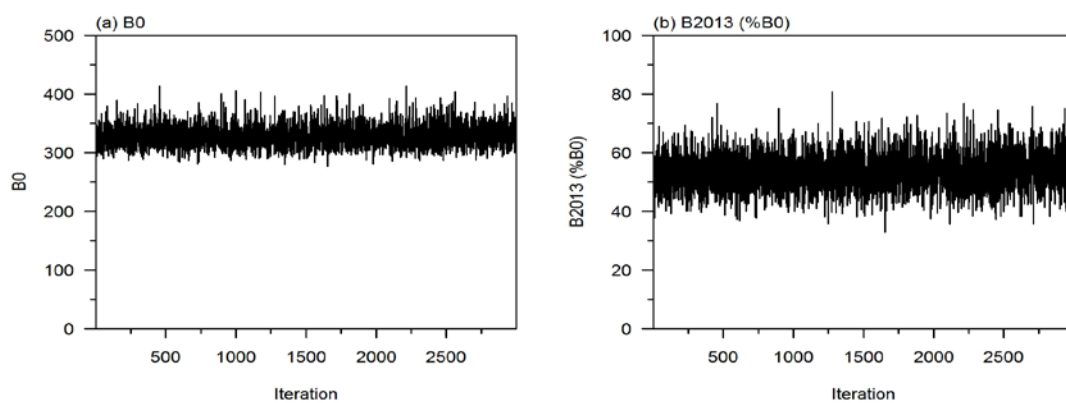
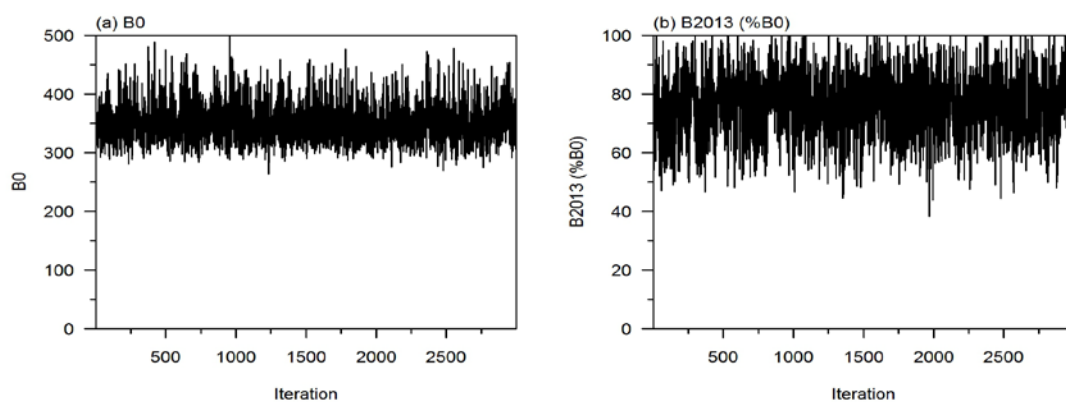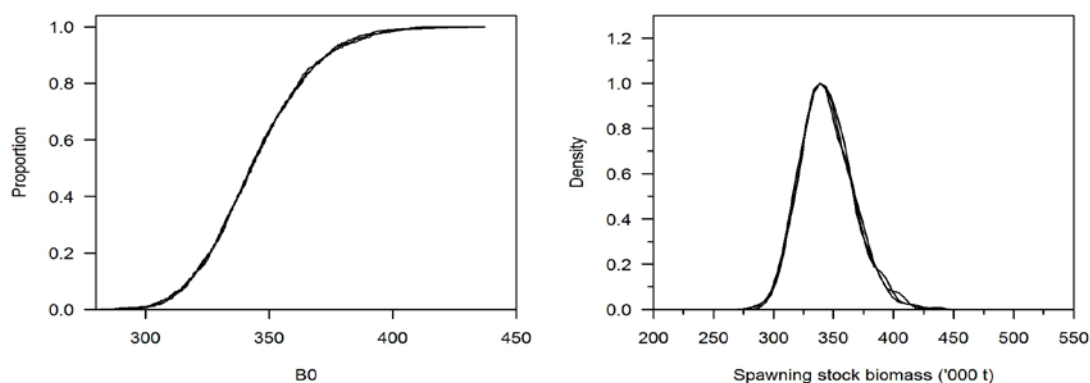**Figure 8: MCMC posterior trace plots for (a) B_0 and (b) current biomass (%B_{2013}/B_0) for run 1.2.**

Figure 9: MCMC posterior trace plots for (a) B_0 and (b) current biomass (%B_{2013}/B_0) for run 1.3.

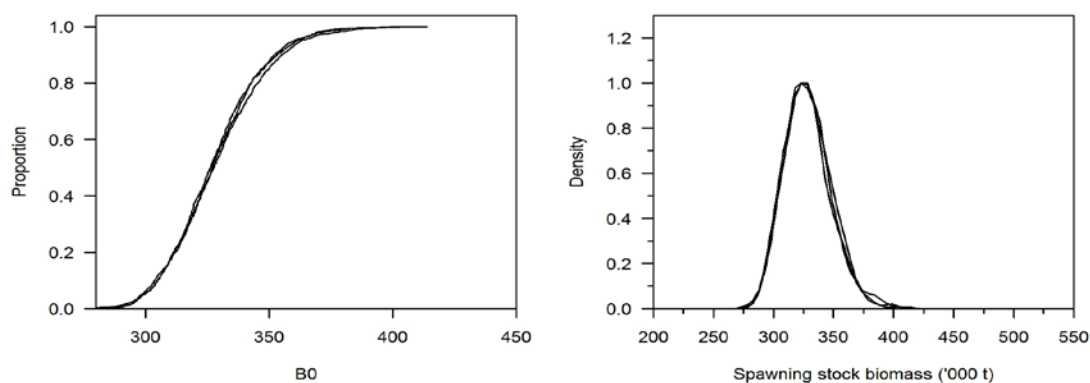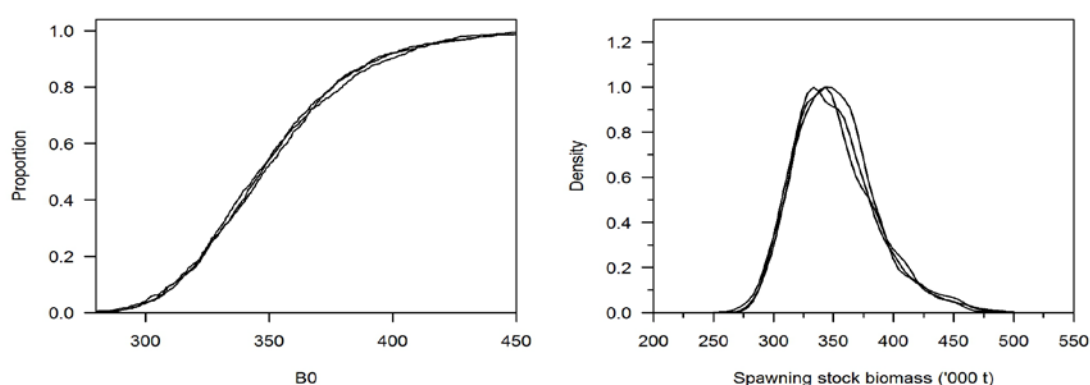**Figure 10: MCMC posterior plots of (a) cumulative density and (b) density for B_0 for three independent MCMC chains for the base case (run 1.1).**

Figure 11: MCMC posterior plots of (a) cumulative density and (b) density for B_0 for three independent MCMC chains for run 1.2.

Figure 12: MCMC posterior plots of (a) cumulative density and (b) density for B_0 for three independent MCMC chains for run 1.3.

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 13 and Figure 14, and the results summarised in Table 6 and Table 7. The run suggests that the stock biomass showed a steady decline from the early 1980s until 1993 followed by a large increase to 1995 as a result of the 1991 year class. The population then declined steadily from 1997 until 2008, and then showed a moderate increase to 2013 as the 2006 and 2009 year classes recruited to the fishery. At the start of the model run in 1979 the biomass was estimated to be at about 45% B_0. During the late 1980s and early 1990s the biomass is 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 biomass is estimated to have been mainly 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.
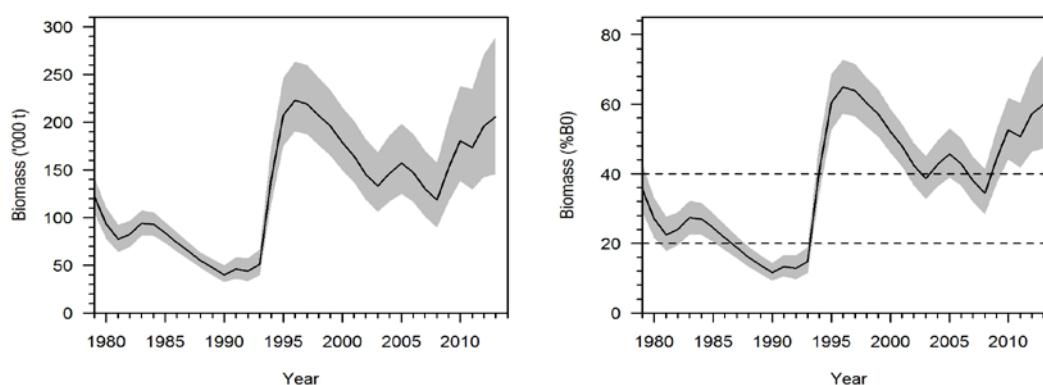
The estimate of the median mature biomass acoustic q was 0.41, which is substantially less than the prior value of 0.87. This would suggest either that the acoustic surveys are substantially underestimating the adult biomass, or that the prior itself is poorly estimated. The estimate of the median immature biomass acoustic q was 0.28, which is substantially less than the estimate for the median mature biomass.

Table 6: Bayesian median and 95% credible intervals of equilibrium (B_0), initial, and current biomass for the model runs 1.1 (base case), 1.2 (exclude 2009 index), and 1.3 (estimate M)
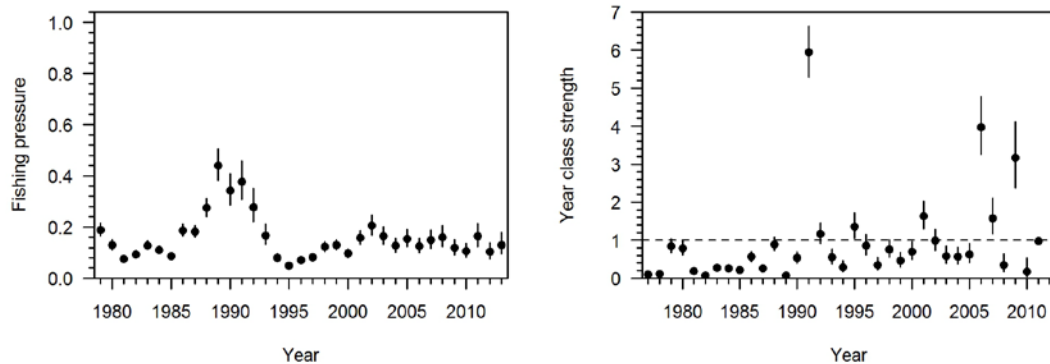
Model	B_0	B_{2013}	B_{2013} (%B_0)
1.1	342 800 (306 910–392 270)	205 422 (145 574–288 908)	60 (47–74)
1.2	326 980 (295 620–369 680)	174 778 (123 574–245 665)	54 (42–67)
1.3	347 080 (297 430–432 550)	263 077 (169 581–410 233)	76 (54–97)

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

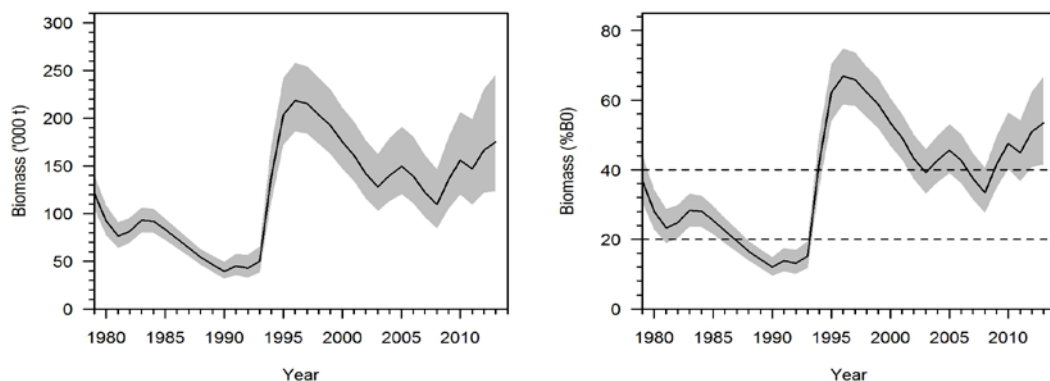| Model	Catchability		Natural mortality	
	Mature	Immature	Male	Female
1.1	0.41 (0.34–0.48)	0.28 (0.22–0.34)	–	–
1.2	0.41 (0.34–0.49)	0.26 (0.21–0.32)	–	--
1.3	0.31 (0.21–0.44)	0.17 (0.10–0.29)	0.26 (0.20–0.31)	0.26 (0.20–0.31)

Figure 13: MCMC median and 90% credible intervals of the trajectory of (left) biomass and (right) biomass (%B_0) for the base case (run 1.1).
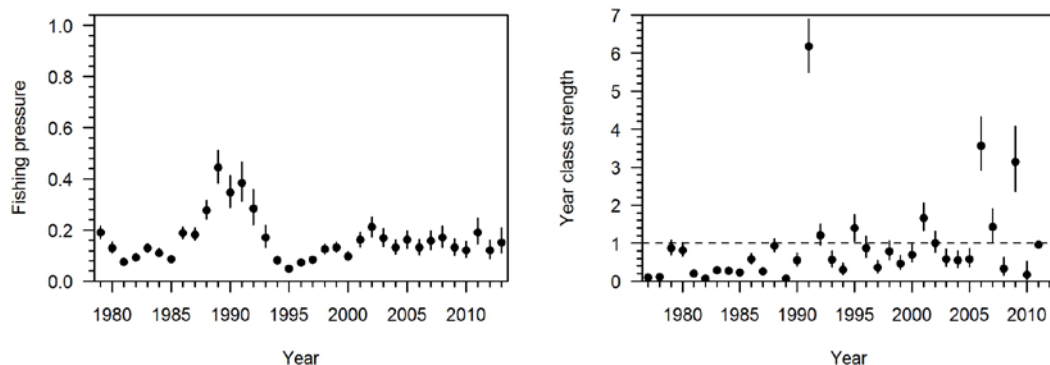
Figure 14: MCMC posterior plots for (left) exploitation rates and (right) relative year class strength for the base case (run 1.1).
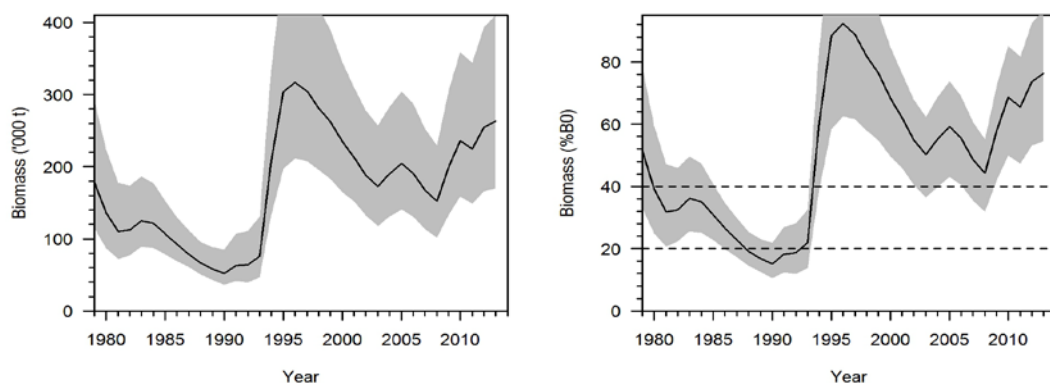
Sensitivity model runs

The estimated MCMC marginal posterior distributions for parameters of interest are shown for the sensitivity tests (model runs 1.2 and 1.3) in Figure 15 to Figure 18, and the results summarised in Table 6 and Table 7. The biomass trajectories show very similar patterns to the base case. The stock status for model run 1.2 is slightly more pessimistic than for the base case, but is still above 50% B_0. In contrast, the stock status for model run 1.3 is more optimistic at 76% B_0. Natural mortality was estimated to be 0.26 y^{-1} for both males and females, which is substantially higher than the value of 0.2 y^{-1} assumed in the base case assessment.

Figure 15: MCMC median and 90% credible intervals of the trajectory of (left) biomass and (right) biomass (%B_0) for run 1.2.

Figure 16: MCMC posterior plots for (left) exploitation rates and (right) relative year class strength for run 1.2.
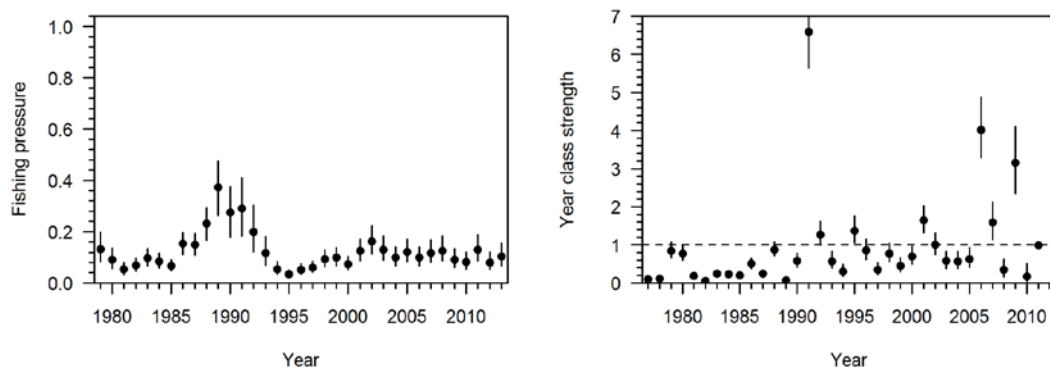

Figure 17: MCMC median and 90% credible intervals of the trajectory of (left) biomass and (right) biomass (%B_0) for run 1.3.

Figure 18: MCMC posterior plots for (left) exploitation rates and (right) relative year class strength for run 1.3.
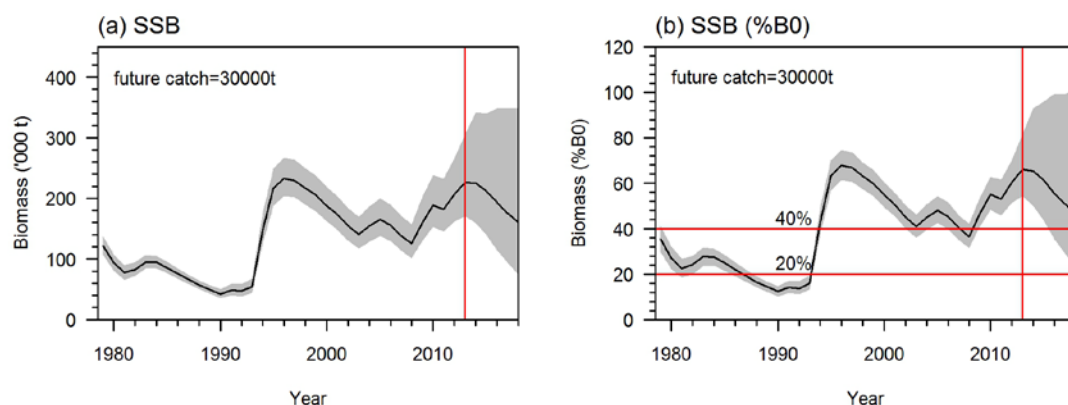
3.3 Projections

Projections were made for the base case model assuming fixed catch levels of 30 000 t, 35 000 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 1977–2010 estimated by the model and applied from year 2011 onwards (Figure 19 to Figure 21). 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 2013 estimates, rather than return to the average size at age that might be expected at lower abundances.
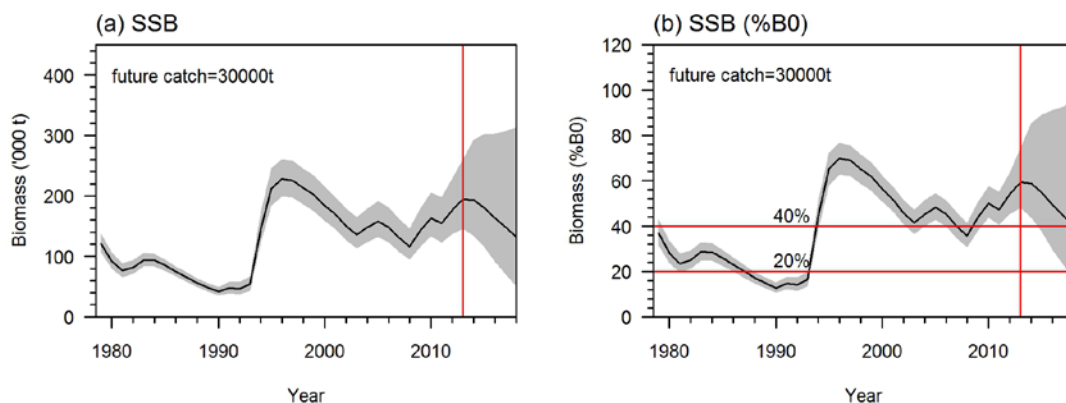
For each scenario, the probability that the mid-season biomass for the specified year will be less than the threshold level (20% B_0) is given in Table 8. The probability of dropping below the threshold biomass at catch levels of 30 000 t was less than 10% for all models and all years. Under average recruitment conditions the biomass is expected to increase in 2014 and then begin to slowly decline.

Table 8: Probability that the projected mid-season vulnerable biomass for 2014–2018 will be less than 20% B_0, and the median projected biomass (%B_0), at a projected catch of 30 000 t, 35 000 t, and 40 000 t, for the base case model (model run 1.1) assuming average recruitment over the period 1997–2010 for 2010+.
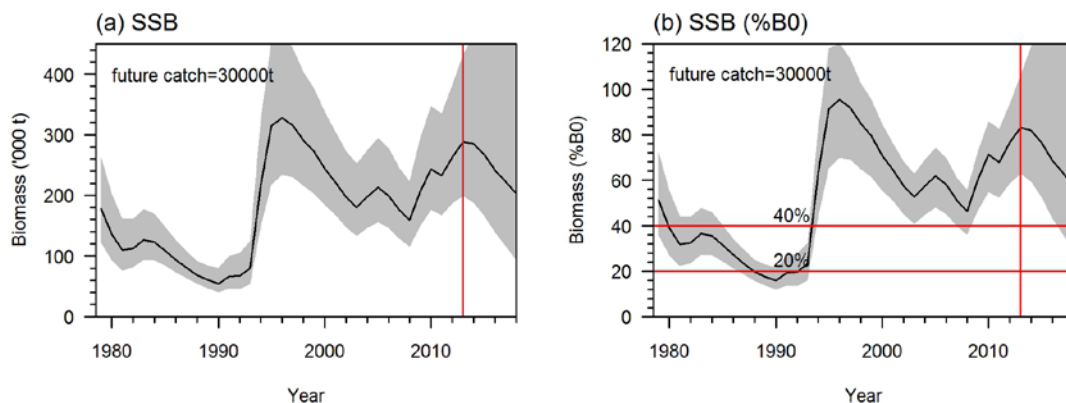
Model	Catch (t)	Pr (SSB < 0.2B_0)					Median SSB (%B_0)				
		2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
1.1	30 000	0.00	0.00	0.00	0.01	0.03	65	61	55	51	46
	35 000	0.00	0.00	0.00	0.02	0.09	64	59	52	46	41
	40 000	0.00	0.00	0.00	0.05	0.18	64	57	49	42	35
1.2	30 000	0.00	0.00	0.00	0.03	0.08	59	55	49	45	40
	35 000	0.00	0.00	0.01	0.07	0.19	58	53	46	40	34
	40 000	0.00	0.00	0.03	0.15	0.32	57	50	42	35	28
1.3	30 000	0.00	0.00	0.03	0.09	0.18	82	76	69	63	57
	35 000	0.00	0.01	0.05	0.15	0.27	81	74	66	59	52
	40 000	0.00	0.01	0.09	0.22	0.37	80	72	63	55	47

Figure 19: MCMC posterior plots for the median (solid line) and 95% credible intervals (dashed lines) for (a) SSB and (b) current biomass (%B_{2013}/B_0) for a catch of 30 000 t for the base case (run 1.1) assuming average recruitment. Horizontal lines indicate 50% and 20% B_0, and the vertical line represents the beginning of the projection period (2014–2018).

Figure 20: MCMC posterior plots for the median (solid line) and 95% credible intervals (dashed lines) for (a) SSB and (b) current biomass ($\%B_{2013}/B_0$) for a catch of 30 000 t for the run 1.2 assuming average recruitment. Horizontal lines indicate 50% and 20% B_0, and the vertical line represents the beginning of the projection period (2014–2018).

Figure 21: MCMC posterior plots for the median (solid line) and 95% credible intervals (dashed lines) for (a) SSB and (b) current biomass ($\%B_{2013}/B_0$) for a catch of 30 000 t for run 1.3 assuming average recruitment. Horizontal lines indicate 50% and 20% B_0, and the vertical line represents the beginning of the projection period (2014–2018).

4. DISCUSSION

The results of the base case assessment found that the biomass of the Campbell Island Rise stock in 2013 was 205 000 t (95% C.I.s 145 600–288 900 t) and was 60% B_0 (95% C.I.s 47–74% B_0). Projections with an annual catch of 30 000 t found that the spawning stock biomass is expected to rise slightly to 65% B_0 in 2014 before declining slowly over the following four year period. There was little difference in the trend in the results between the base case and the two sensitivity models, although model 1.2 (exclude 2009) was less optimistic in the current status and projected status and model 1.3 (estimate *M*) was more optimistic.

The assessment was strongly influenced by the high biomass estimates from the 2009 and 2011 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 seriously doubt that the 2006 and 2009 year classes are strong, but the size of these year classes is still not well estimated. The relative strength of these year classes differed slightly between the models with the 2009 year class being stronger than the 2006 year class.

. Estimates of B_{1979} and the stock trajectory up to 2011 were similar to the previous assessment, but the current model had several slight differences: (i) a slightly lower biomass in 2011, (ii) a slightly lower B_0, and (iii) a much lower estimate of the 2007 year class. As discussed above the main drivers for the slight decrease in biomass are the lower estimates of adult biomass in the 2011 and 2013 acoustic surveys compared to the 2009 survey. A new survey is being conducted in September 2015, 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 is the estimate of B_0. B_0 has been poorly estimated in southern blue whiting models as a consequence of few very strong year classes strongly influencing estimates of average recruitment. In recent years, the influx of a few new and very 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 increased to 396 000 t in the 2011 assessment (Dunn & Hanchet 2013) and has since reduced to 343 000 t in the current assessment.

The estimate of the median mature biomass acoustic q was 0.41 for the base case and model 1.2, and 0.31 for model 1.3. These estimates were substantially lower than the mean of the prior of 0.87. This suggests that either the acoustic surveys substantially underestimate the adult biomass or that the acoustic adult biomass prior may not have been well specified. The main uncertainty in the estimate of the prior comes from assumptions of the target strength fish length relationship. The log-normal prior was developed for the wide area acoustic survey catchability coefficient with mean 0.87 and CV 0.3, obtained using the approach of Cordue (1996) and was derived by P. Cordue (pers. comm., 2013). This was aggregated over various factors including mean target strength, acoustic system calibration, target identification, shadow/dead zone correction, and spatial availability (see Table 4). While this analysis gave a mean value of 0.87, the analysis did not account for recent updates to the target strength of southern blue whiting based on *in situ* measurements using an acoustic-optical system (AOS) (O'Driscoll et al. 2013). The AOS target strength estimate was based on observations of fish in the mouth of a trawl, which had a mean swimming angle of 16° and standard deviation of 15°. This was likely to have over-estimated target strength of fish in spawning aggregations, as spawning fish may have a different mean tilt angle and are likely to have a greater tilt distribution to those being herded into a trawl. We note that further work may be required to determine the average tilt angle of southern blue whiting in situ, so that this prior can be better 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). Review and summary of the time series of input data available for the assessment of southern blue whiting (*Micromesistius australis*) stocks in 2014. *New Zealand Fisheries Assessment Report 2015/56*. 45 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.

Geweke, J. (1992). Evaluating the accuracy of sampling-based approaches to calculating posterior moments. *In*: Bayesian Statistics, 4. Bernardo, J.M.; Berger, J.O.; Dawid, A.P.; Smith, A.F.M. (eds.). Clarendon Press, Oxford. pp 169−194.

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.; 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.

Heidelberger, P.; Welch, P. (1983). Simulation run length control in the presence of an initial transient. *Operations Research 31*: 1109–1144.

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 bluewhiting (*Micromesistius australis*). *ICES Journal of Marine Science* 70: 431–439.

Smith, B.J. (2003). Bayesian output analysis program (BOA). Version 1.0 user's manual. Unpublished manuscript. 45 p. University of Iowa College of Public Health. (*see* http://www.public-health.uiowa.edu/boa)