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Stock assessment of Sub-Antarctic hake (part of HAK 1) for 2018

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EXECUTIVE SUMMARY

Dunn, M.R. (2019). Stock assessment of Sub-Antarctic hake (part of HAK 1) for 2018.

***New Zealand Fisheries Assessment Report 2019/52*. 29 p.**

This report summarises the stock assessment of hake (*Merluccius australis*) in New Zealand Quota Management Area HAK 1 south of latitude 46° S (the Sub-Antarctic) for the 2017–18 fishing year. An updated Bayesian assessment was conducted using the general-purpose stock assessment program CASAL v2.30. The assessment incorporated all relevant biological parameters, the commercial catch history, research trawl survey biomass indices, proportion-at-age data from the commercial trawl fishery and research survey series, and commercial fishery catch-per-unit-effort (CPUE) biomass indices. The analysis includes fishery data up to the end of the 2016–17 fishing year.

The previous assessment had estimated natural mortality rate (M) at age to be U-shaped, implying relatively high juvenile and older-adult (senescence) mortality. This assumption was removed in the 2017–18 assessment in favour of constant M at age. The previous assessment estimated the recent stock biomass trajectory to be flat. The 2017–18 assessment revised this to a declining trend, influenced by relatively low survey biomass estimates in 2015 and 2017, with 2017 being the lowest in the time series. The influence of the assumed prior variability in year class strengths (σ_R) was found to be influential on the results, but the model contained little information on its true value; the final models therefore assumed two alternative values. Model runs using CPUE as a biomass index in place of the research surveys did not perform well, and were excluded from the set of final model runs.

The base model in 2017–18 estimated that the Sub-Antarctic spawning stock had been reduced to about 50% of a virgin biomass (B_0) of about 55 000 t. This compares to about 60% and 59 000 t from the previous assessment. The assessment estimated that the stock in 2017–18 was above the target level of depletion, had never been overfished, overfishing had never taken place, and at current catch levels (about 1400 t) was likely to remain stable. However, at catch levels approaching the TACC (3701 t) the stock size was likely to decline.

1. INTRODUCTION

This report describes the stock assessment of hake (*Merluccius australis*) in the Sub-Antarctic region of New Zealand Quota Management Area (QMA) HAK 1 (HAK 1 south of latitude 46° S), with the inclusion of data up to the end of the 2016–17 fishing year (New Zealand fishing years start 1 October). The report provides additional detail to the stock assessment that took place in 2018, described in the Fisheries Assessment Plenary (Fisheries New Zealand 2019). The current stock hypothesis for New Zealand hake suggests that there are three stocks; the west coast South Island stock, the Sub-Antarctic stock, and the Chatham Rise stock. This assumption requires the HAK 1 QMA to be split at the southern boundary of Chatham Rise (Figure 1).

This report describes the research conducted under objective two of Fisheries New Zealand Project HAK20147/01. Specific project objective two was: *To update the stock assessment of the sub-Antarctic hake stock including estimates of current biomass, the status of the stock in relation to management reference points, and future projections of stock status as required to support management*.

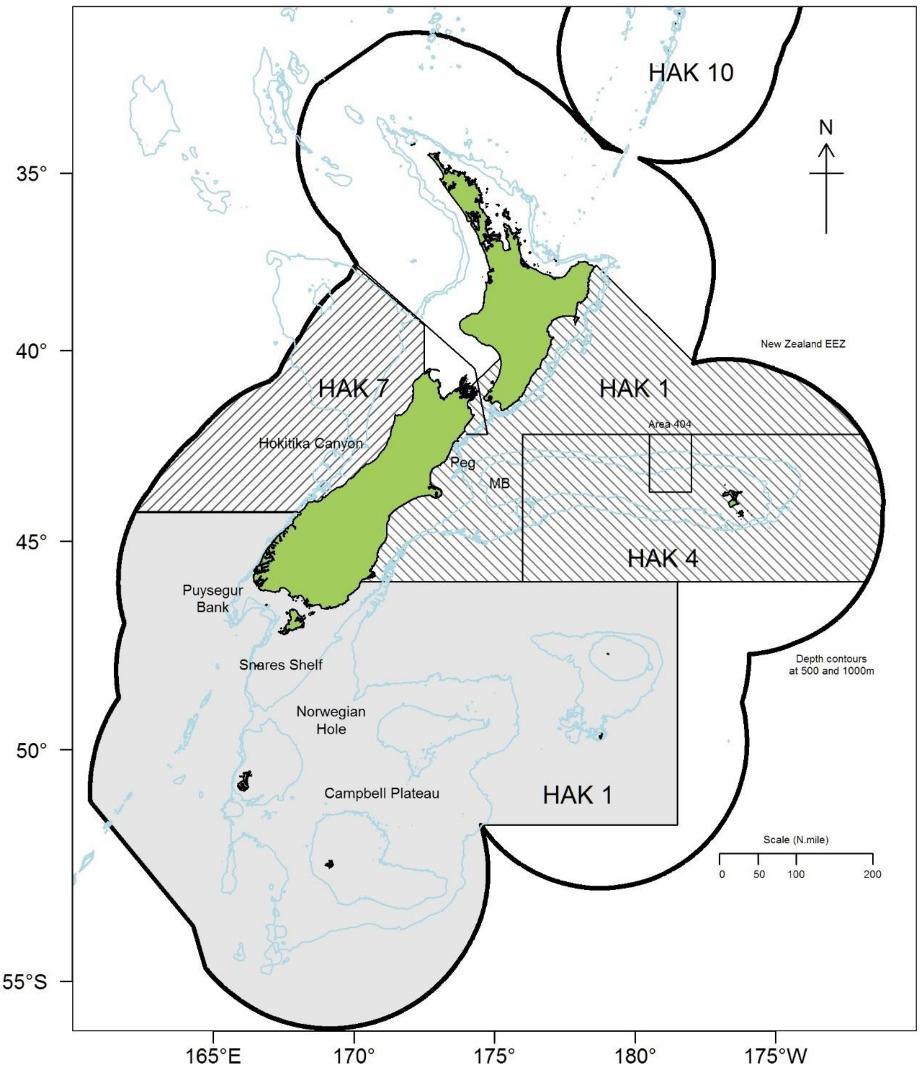

Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, and 10, and hake biological stock boundaries, as assumed in this report: West coast South Island (dark stripes over HAK 7), Chatham Rise (light stripes over HAK 1 and HAK 4), and Sub-Antarctic (grey shading over HAK 1). Peg, Pegasus Bay; MB, Mernoo Bank.

2. ASSESSMENT INPUT DATA

There were five main data sources: the catch history; research trawl survey biomass indices from November–December 1992–2017, April–May 1992–98, and September 1992; catch-at-age estimates from the research surveys; catch-at-age estimates from the commercial fishery 1990 to 2017, and a commercial CPUE biomass index 1991 to 2017 (not used in the base model). These are the same inputs as used in the previous assessment (Horn 2015), with the inclusion of two additional research trawl surveys (2015 and 2017), and three additional years of Fisheries New Zealand observer samples of catch composition (2015 to 2017).

2.1 Catch history

The history of the fishery, including catch estimates, was described in detail by Ballara (2018), and summarised in Table 1. The reported catch (Fisheries New Zealand 2019) was assumed to be entirely from trawls, and the assessment model assumed all catches were from a single trawl fishery. Catches for the assessment year (2018) were assumed to be the same as the last year for which data were available (2017). The catch history was assumed to be accurate and without error. Sensitivity to alternative catch histories was not investigated here, but the influence of selected alternative catch histories for HAK 1 was evaluated by Horn et al. (2018).

Table 1: Commercial catch history (t) for the HAK 1 Sub-Antarctic stock. Note that from 1990 totals by model year differ from those for fishing year (see Fisheries New Zealand 2019) because the September catch had been shifted from the fishing year into the following model year.

Model year	Total	Model year	Total
1975	120	1997	1 915
1976	281	1998	2 958
1977	372	1999	2 854
1978	762	2000	3 108
1979	364	2001	2 820
1980	350	2002	2 444
1981	272	2003	2 777
1982	179	2004	3 223
1983	448	2005	2 592
1984	722	2006	2 541
1985	525	2007	1 711
1986	818	2008	2 329
1987	713	2009	2 446
1988	1 095	2010	1 927
1989	1 237	2011	1 319
1990	1 897	2012	1 900
1991	2 381	2013	1 859
1992	2 810	2014	1 800
1993	3 941	2015	1 600
1994	1 596	2016	1 464
1995	1 995	2017	1 033
1996	2 779	2018	1 033

2.2 Biological parameters

All biological parameters other than natural mortality rate, M, were estimated from previous studies, outside of the model. Estimated and assumed values for biological parameters used in the assessment are given in Table 2. Growth was constant and followed the Schnute parameterisation. Natural mortality rate, M, was constant, and estimated with an informed prior derived from expert opinion (Table 3). A Beverton-Holt stock recruitment relationship was used with an assumed steepness, h, of 0.8. Year class strengths were estimated for the period 1974–2016, following the Haist parameterisation, with a lognormal prior on YCS having an assumed CV of 0.7 in the base model. Ageing error was assumed (with C.V. = 0.08). All mature fish were assumed to spawn every year.

Table 2: The assumed biological parameters for the HAK 1 Sub-Antarctic stock assessment.

Proportion mature at age			Growth and *M*		
Age	male	female	Schnute growth (cm)	male	female
2	0.01	0.01	Y1	22.3	22.9
3	0.03	0.02	Y2	89.8	109.9
4	0.09	0.05	Tau1	1.0	1.0
5	0.22	0.11	Tau2	20.0	20.0
6	0.46	0.23	a	0.249	0.147
7	0.71	0.43	b	1.243	1.457
8	0.88	0.64	CV	0.1	0.1
9	0.96	0.81			
10	0.98	0.91	Length (cm) – weight (t)		
11	0.99	0.96	a	2.13×10^{-9}	1.83×10^{-9}
12	1.00	0.998	b	3.281	3.314
13	1.00	0.99			
14	1.00	1.00	Natural mortality rate (yr^{-1})	0.19	0.19

Table 3: The assumed priors for key distributions (when estimated) for the HAK 1 Sub-Antarctic stock assessment. The parameters are mean and standard deviation or CV in normal space.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	5 000	350 000
Year class strengths	Lognormal (μ, cv)	1.0	0.7	0.01	100
Trawl survey q[1]	Lognormal (μ, cv)	0.16	0.79	0.01	0.4
CPUE q	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	1	20–200[2]
M	Normal (μ, sd)	0.19	0.05	0.05	0.40

[1] Three trawl survey q values were estimated, but all had the same priors.
[2] A range of maximum values was used for the upper bound.

2.3 Research trawl surveys

The November to December Sub-Antarctic trawl survey series was summarised by Bagley et al. (2013). Documentation of the 2017 survey was not yet published at the time of writing; the previous survey was described by Bagley et al. (2017). The hake biomass estimated from the research trawl surveys are given in Table 4.

The priors for survey qs were estimated by assuming that q was the product of areal availability, vertical availability, and vulnerability (Fisheries New Zealand 2019). A prior was then determined by assuming that the resulting, sampled, distribution was lognormally distributed. Values assumed for the parameters were; areal availability (0.50–1.00), vertical availability (0.50–1.00), and vulnerability (0.01–0.50). The resulting (approximate lognormal) distribution had mean 0.16 and CV. 0.79, with bounds assumed to be (0.01–0.40) (Table 3).

Table 4: Research survey indices (and associated CVs) for the HAK 1 Sub-Antarctic stock.

		Nov–Dec series [1]		Apr–May series [2]		Sep series [2]	
Fishing year	Vessel	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1989*	*Amaltal Explorer*	2 660	0.21	–	–	–	–
1992	*Tangaroa*	5 686	0.43	5 028	0.15	3 760	0.15
1993	*Tangaroa*	1 944	0.12	3 221	0.14	–	–
1994	*Tangaroa*	2 567	0.12	–	–	–	–
1996	*Tangaroa*	–	–	2 026	0.12	–	–
1998	*Tangaroa*	–	–	2 554	0.18	–	–
2001	*Tangaroa*	2 657	0.16	–	–	–	–
2002	*Tangaroa*	2 170	0.20	–	–	–	–
2003	*Tangaroa*	1 777	0.16	–	–	–	–
2004	*Tangaroa*	1 672	0.23	–	–	–	–
2005	*Tangaroa*	1 694	0.21	–	–	–	–
2006	*Tangaroa*	1 459	0.17	–	–	–	–
2007	*Tangaroa*	1 530	0.17	–	–	–	–
2008	*Tangaroa*	2 470	0.15	–	–	–	–
2009	*Tangaroa*	2 162	0.17	–	–	–	–
2010	*Tangaroa*	1 442	0.20	–	–	–	–
2012	*Tangaroa*	2 004	0.23	–	–	–	–
2013	*Tangaroa*	1 943	0.25	–	–	–	–
2015	*Tangaroa*	1 477	0.25	–	–	–	–
2017[3]	*Tangaroa*	1 000	0.25	–	–	–	–

* Not used in the assessment.

Notes: (1) Series based on indices from 300–800 m core strata, including the 800–1000 m strata in Puysegur, but excluding Bounty Platform; (2) Series based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in Puysegur and the Bounty Platform; (3) Due to bad weather, the core survey strata were unable to be completed in 2017; biomass estimates were scaled-up using factors based on the proportion of hake biomass in those strata in previous surveys from 2000 to 2014. This introduced additional uncertainty into the 2017 biomass estimate (O'Driscoll, NIWA, pers.comm.)

2.4 Catch-at-age

Catch-at-age observations were available for each trawl survey of the Sub-Antarctic, and for the commercial fisheries from Fisheries New Zealand observer samples (Table 5). A plus group for all the catch-at-age data was set at 21 with the lowest age set at 3. Proportions-at-age distributions were fitted assuming multinomial errors, with an effective sample size set following the iterative reweighting procedure of Francis (2011). No age distribution was available for the 2017 RV *Tangaroa* survey, because only 33 hake were caught. Before reweighting, the effective sample sizes of commercial proportions-at-age were halved for all years except 1996–2000, 2011, 2014, and 2016–17, because the age data used included the age samples from the research surveys, and these age data were therefore used twice in the model inputs.

2.5 CPUE

A commercial catch-per-unit-effort index provided an alternative biomass index (Ballara 2018). Commerical CPUE were considered a less reliable biomass index than the research trawl surveys, and therefore were not used in the base model runs (Table 6).

Table 5: Catch-at-age data for the HAK 1 Sub-Antarctic stock, giving the multinomial effective sample sizes assumed for each sample. The effective sample size is proportional to the weight given to the data in the model fit.

	Research survey			
Fishing year	Nov-Dec	Apr-May	September	Commercial trawl
1990	19	–	–	7
1991	–	–	–	–
1992	21	16	17	17
1993	30	16	–	14
1994	36	–	–	5
1995	–	–	–	–
1996		12		10
1997	–	–	–	–
1998		13		16
1999	–	–	–	31
2000	–	–	–	49
2001	58	–	–	14
2002	46	–	–	21
2003	52	–	–	10
2004	38	–	–	18
2005	30	–	–	6
2006	40	–	–	21
2007	51	–	–	6
2008	49	–	–	16
2009	59	–	–	18
2010	45	–	–	31
2011	–	–	–	48
2012	49	–	–	42
2013	60	–	–	16
2014	–	–	–	47
2015	22	–	–	18
2016	–	–	–	31
2017	–	–	–	31

Table 6: Commercial trawl CPUE index for the HAK 1 Sub-Antarctic stock, giving the lognormal mean and CV.

Fishing year	Index	CV	Fishing year	Index	CV
1991	1.18	0.1	2005	0.95	0.04
1992	1.51	0.05	2006	0.81	0.05
1993	1.44	0.05	2007	0.66	0.04
1994	1.3	0.06	2008	0.75	0.04
1995	1.08	0.05	2009	0.88	0.05
1996	0.97	0.05	2010	0.97	0.05
1997	1.13	0.04	2011	0.81	0.05
1998	1.11	0.03	2012	0.84	0.05
1999	1.46	0.04	2013	0.85	0.04
2000	1.3	0.03	2014	0.58	0.04
2001	1.31	0.03	2015	0.54	0.04
2002	1.06	0.03	2016	0.65	0.05
2003	1.01	0.03	2017	0.55	0.04
2004	1.29	0.04			

3. ASSESSMENT MODELLING

3.1 Research since the last assessment

The previous stock assessment of HAK 1 was completed in 2014, when B_{2014} was estimated at 60% B_0, very likely to be at or above the target level of depletion (40% B_0), with overfishing very unlikely to be occurring (Horn 2015). Biomass was estimated to have been increasing since 2010.

Inter-sessional work on hake in New Zealand since the last assessment included the continued collection of monitoring data (random research trawl surveys and catch-at-age sampling), and a study on the influence of alternative catch histories on the stock assessment (Horn et al. 2018). Under the scenarios considered by Horn et al. (2018), when historical catches were higher, B_0 and current biomass increased, and when historical catches were lower, B_0 and current biomass decreased , but stock status remained largely unchanged. This work was in response to the analyses presented in Simmons et al. (2016).

An analysis for Chilean hake (subspecies of *M. australis*) estimated stock-recruitment steepness (h) to be 0.7 (95% CI 0.34–0.94) (Wiff et al., 2018). This is not much different from the 0.8 assumed in New Zealand assessments.

Elemental analyses of South American hake otoliths was used to evaluate stock structure, and concluded that hake off the west (Chilean) and east (Falklands Islands) coasts of South America were not significantly different, leading to a conclusion that there was just one stock (Brickle et al., 2016). This was despite the substantial geographical distances between the sample sites, and that Falkland Island fish reached larger sizes than their Chilean counterparts. This conclusion would imply that hake was a highly migratory species. There has also been some recent research on the South American hake genome (Reyes et al. 2016).

3.2 Development of the 2019 model

The 2018 stock assessment was implemented as a Bayesian model using the general-purpose stock assessment program CASAL v2.30 (Bull et al. 2012).

The model had a single area, and was sex and age-structured, partitioned into age groups 1–30 with the last age group considered a plus group. Although the model kept track of numbers by sex, the observations were all for sexes combined. There were two annual time steps, Sep-Feb and Jun-Aug, to allow for different timings of the research trawl surveys. Growth, recruitment, maturation, spawning, and fishing took place in time step one, but M was apportioned between the two time steps. M was assumed to be constant, and was estimated. Maturity at age and growth were fixed. Relative year class strengths were estimated.

The model was initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1974–2014. The selectivity for the fishery was assumed to be logistic, and the selectivities were domed (double normal) for each of the November–December and April–May trawl survey series (with the September 1992 survey assumed to have a selectivity equal to the April–May series). Selectivities were assumed constant across all years in the fishery and the surveys, and hence there was no allowance for possible annual changes in selectivity. Selectivities for the trawl surveys were all assumed to be double normal, and for the trawl fishery logistic.

Biomass indices were fitted with lognormal likelihoods with assumed CVs set equal to the sampling CV. The CVs (for observations fitted with lognormal likelihoods) are assumed to have allowed for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance for all observations in all model runs (a "process error"). A process error of 0.2 was added to all survey biomass indices following the recommendation of Francis et al. (2001). For the CPUE index, the process error CV was assumed to be 0.25.

For investigative model runs, parameters were estimated at the Maximum of the Posterior Density (MPD). For final model runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm, with a chain length of 11 million, re-estimating the covariance matrix at 0.5 million, discarding the first 1 million, then keeping every 1000th sample.

In the base model, the main parameters estimated therefore were: virgin biomass (B_0), natural mortality rate (M), trawl survey selectivities for the Nov-Dec series (3 parameters), trawl survey selectivities for the April and September series (3 parameters), trawl fishery selectivity (2 parameters), catchabilities (q) for the trawl surveys (3 parameters), or trawl fishery CPUE (in the CPUE sensitivity run; 1 parameter), and year class strengths (YCS) from 1974 to 2016 (43 parameters).

3.2.1 The *M* assumption

The previous assessment assumed a U-shaped *M*, where the increase in *M* in older fish might be assumed to be a result of senescence (Horn 2015). This assumption is similar to that used in the hoki assessment (Fisheries New Zealand 2019), where it has also been considered plausible, but can also be considered to be a “tactical” assumption. It is “tactical” in that it is a response to old fish being observed in lower proportions than expected; to fit the observations these old fish were either dead (from *M*), or unavailable (i.e., domed selectivity), and the former was preferred because it did not generate unavailable (cryptic) spawning biomass. In hake assessments assuming U-shaped *M* there has been no prior on any *M* model parameters, nor on the resulting *M* at age; the hoki assessment has included the latter.

In a HAK 1 assessment assuming U-shaped *M*, likelihood profiles revealed that stock status (%B_0) remained the same despite B_0 being varied. This result was possible because *M* changed, specifically the *M*-at-age changed shape (Figure 2). At B_0 above about 75 kt, the model could maintain a similar fit to data despite changes in average *M* (Figure 3); note that there was no prior on the *M*, so such changes (to *M* values becoming implausible for the observed longevity of hake) were not penalized in the model.

The fit of the model was little different when the *M* assumption was changed from U-shaped to constant at age. Although the fit to the proportions-at-age data was not as good with the constant *M* assumption, by about 15 likelihood units, this difference was spread across 47 proportions-at-age observations and the visual difference in fit was negligible (Table 7). The fit to the November-December biomass index improved slightly with the constant *M* assumption and logistic rather than domed trawl fishery selectivity, by about one likelihood unit; this improvement in fit was visible but not large.

Table 7: Sensitivity runs for *M* and selectivity assumptions for the hake HAK 1 assessment model, showing parameter estimates and likelihoods for key observations. Selectivity for the research trawl survey remained domed in all of these runs. VB, trawl fishery vulnerable biomass. *M* reported for the U-shaped assumption is the mean over ages 7–15.

				Run assumptions
M	U-shaped at age	U-shaped at age	Constant at age	Constant at age
Fishery selectivity	Double normal	Logistic	Double normal	Logistic
				Parameter estimates
M	0.22	0.23	0.12	0.20
B_0	59 760	59 070	111 060	55 000
$\%B_0$	52	53	53	45
VB_{2000}/SSB_{2000}	97	100	50	100
				Likelihoods
Tan index Nov-Dec	-13.08	-13.11	-13.59	-40.20
Tan Nov-Dec prop.-at-age	372.99	373.13	377.89	385.14
Fishery prop.-at-age	394.97	395.63	394.80	398.10

During the assessment review process (Fisheries New Zealand Deepwater Working Group meetings), a constant *M* at age was argued, and accepted, in favour of a U-shaped *M* because (1) it avoided confounding U-shaped *M* with domed selectivity; (2) the model apparently had little information on *M*-at-age, i.e., fits did not clearly distinguish between alternative *M* assumptions; (3) informed priors for parameters of the U-shaped *M* could not be developed; (4) a U-shaped *M* for a large teleost seemed biologically hard to justify (e.g., Nussey et al. 2013); and (5) there was no clear tactical need for a U-shaped *M*. The five-parameter U-shaped *M* model was abandoned in favour of a simpler, and more conventional, constant *M* at age.

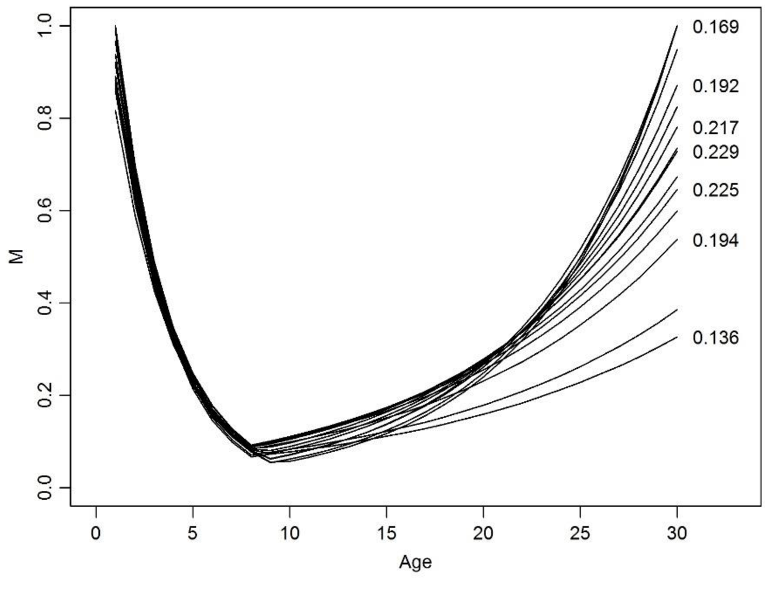

Figure 2: Hake HAK 1 natural mortality rate *M* at age in the initial assessment model, at different fixed B_0 levels (lines). Labels show mean *M* across ages 7–15 for selected model runs.

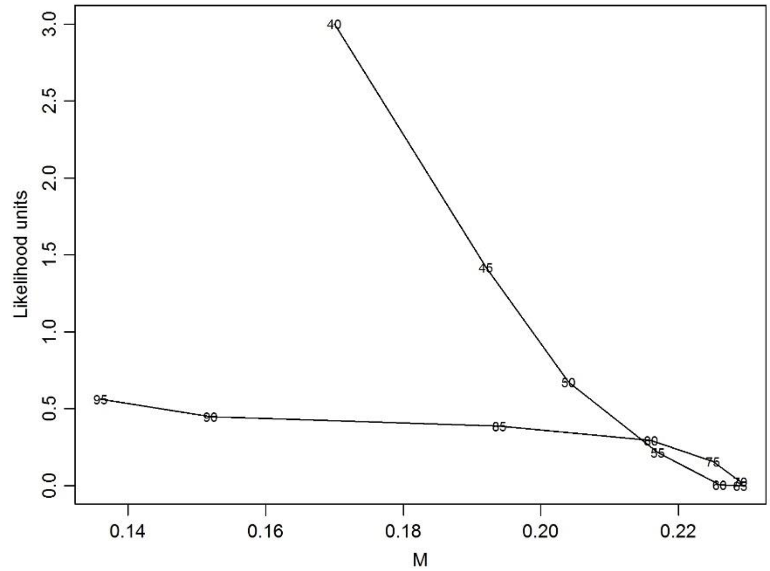

Figure 3: Hake HAK 1 objective function (as difference in likelihood) and mean natural mortality rate *M* across ages 7–15 for different runs of the initial model having different fixed B_0 (B_0 in kt shown as labels)

3.2.2 The updated SSB trajectory

The updated base model estimated a stock status (52% B_0) that was lower than the previous assessment (60% B_0; Horn 2015) (Figure 4). The less optimistic terminal biomass trend was caused by the inclusion of relatively low research trawl biomass indices in 2015 and 2017 (Figure 5).

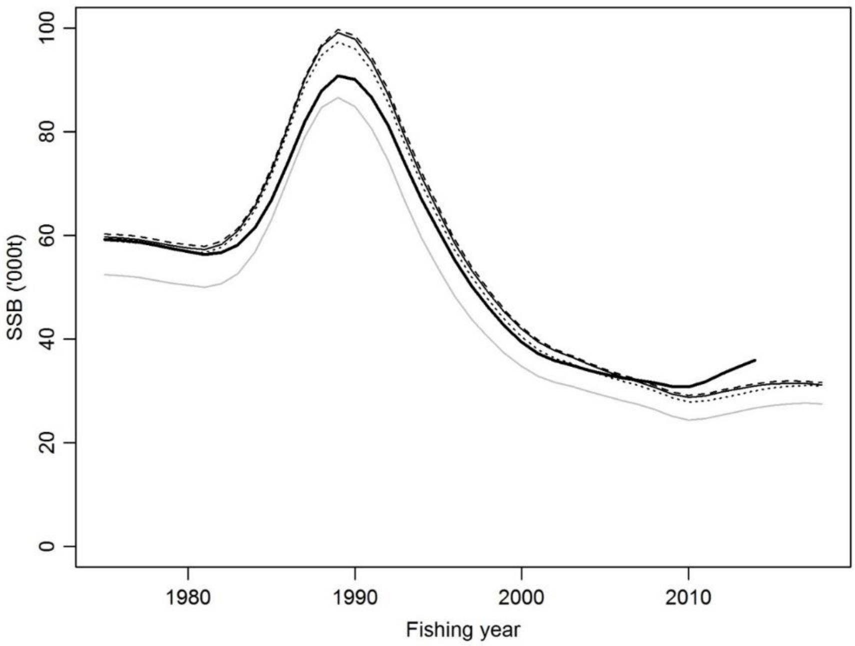

Figure 4: Change in hake HAK 1 estimated biomass trajectory as the assessment model was updated from the previous (2015) assessment to current (2018). The previous assessment is shown as the solid black line (ends in 2015); the group of trajectories starting at an SSB of around 60 kt represent trajectories after updates to the annual cycle, and model reweighting; the grey trajectory starting at a lower SSB of about 52 kt is the model after fishery selectivity was changed from domed to logistic.

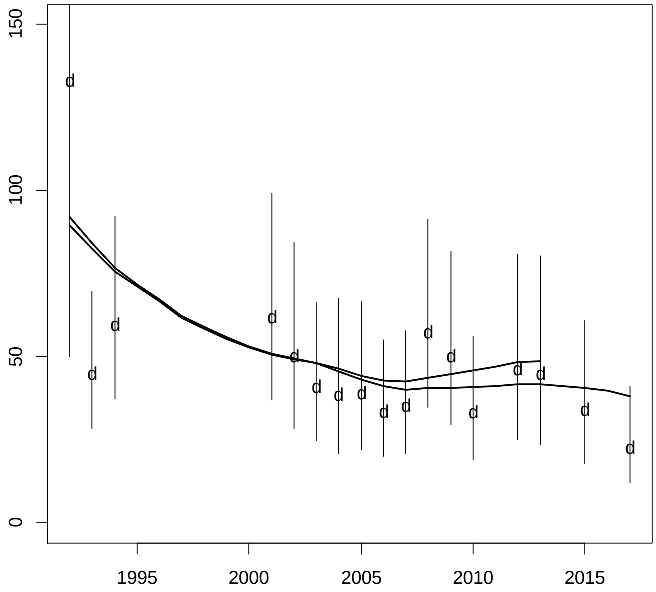

Figure 5: The hake HAK 1 biomass trajectory (line) fitted to the RV *Tangaroa* November-December biomass index (labelled 'd', with 95% CI) to 2013 (i.e., previous assessment) and 2017 (current assessment).

In addition, the 2015 assessment estimated some relatively good year classes entering the fishery from 2004–2007, but the current assessment estimated these to be weaker, and of a similar size to those of the 1990s (Figure 6).

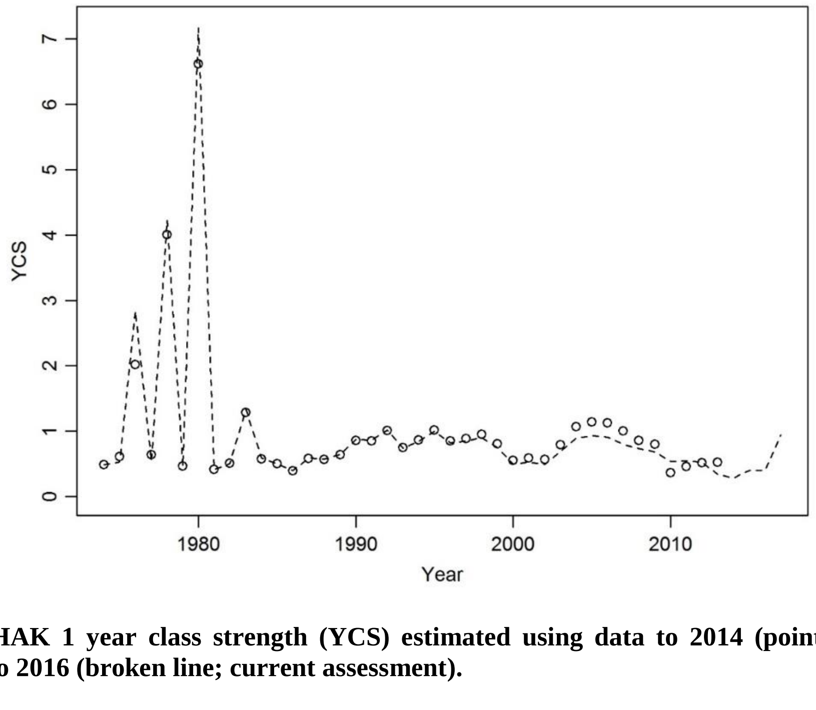

Figure 6: Hake HAK 1 year class strength (YCS) estimated using data to 2014 (points; i.e., previous assessment) and to 2016 (broken line; current assessment).

If the last (2017) RV *Tangaroa* November-December survey was excluded, the model estimated a slightly larger stock that was slightly less depleted (Figure 7). This sensitivity was included because the Fisheries New Zealand Working Group was concerned by the small hake sample size resulting from reduced survey coverage in 2017. Excluding the first survey, which was relatively high but especially uncertain, made negligible difference to the outcome. Ultimately, no surveys were excluded from final model runs.

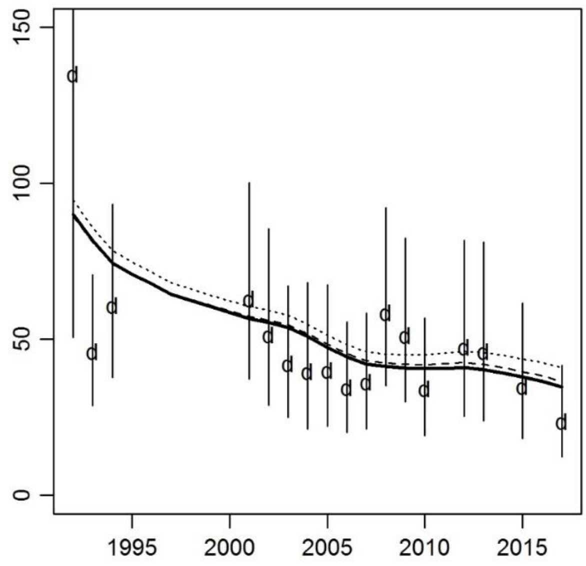

Figure 7: Hake HAK 1 estimates of biomass vulnerable to the RV *Tangaroa* November-December trawl survey (labelled 'd' with 95% CI) for the initial model run (solid line), and after excluding the first (dashed line) or last (dotted line) year of the biomass index.

3.2.3 Sensitivity to the assumed σR prior

The model estimated that there were some very large cohorts before 1980 (Figure 6). These cohorts were clearly visible in the observations, but the model tended to underestimate their size (see Section 4.1.2). Whether the assumed variability of year class strengths in the prior (σ_R) might be restricting this fit was therefore investigated. The estimated CV of year class strengths (σ_R) did not exceed around 1.5 as the CV of the prior was increased (Figure 8). As σ_R was varied there were negligible changes in the fits to observations, but there was some change in B_0 and stock status (Table 8). Therefore, final model runs assumed either a σ_R of 1.1 (to follow Horn 2015), or 0.7 (following Francis & Fu 2015).

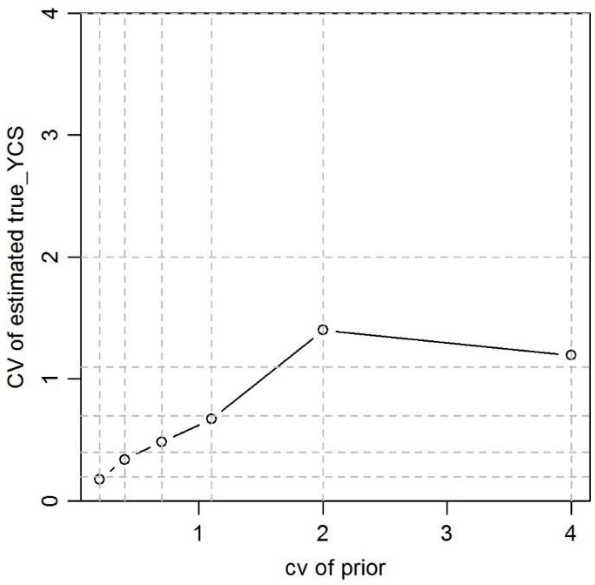

Figure 8: Coefficient of variation (CV; lognormal) of estimated hake HAK 1 year class strength after assuming different values of σ_R for the year class strength prior.

Table 8: Selected likelihoods and parameter estimates for the hake HAK 1 proportions-at-age observations under different assumed priors for year class strength CV (σ_R).

					σ_R
	0.2	0.4	0.7	1.1	2.0
Tangaroa April prop.-at-age	-3.75	-4.07	-4.32	-4.34	-4.53
Tangaroa Nov-Dec prop.at-age	-14.14	-14.46	-14.64	-14.20	-12.61
Tangaroa September prop.-at-age	-1.35	-1.40	-1.40	-1.39	-1.37
Fishery prop.-at-age	401.86	398.11	398.00	398.10	398.61
Difference in likelihood	+4.98	+0.54	0	+0.53	+2.46
					Parameter estimates
B_0 (kt)	46.4	49.6	52.9	55.1	65.8
% B_0	57.0	56.7	51.3	44.7	36.7

3.2.4 Using fishery CPUE as the biomass index

Previous analyses had shown that adding CPUE to a model already including the research trawl surveys did not add any information on stock size (Horn 2015). A sensitivity run using commercial CPUE as the biomass index instead of research trawl biomass was completed. The Fisheries New Zealand Working Group selected the CPUE index based upon TCEPR form tow-by-tow data. An additional "process" error of 0.15 was added to the CPUE observation errors (from the GLM analyses) following Francis (2011). All models using the CPUE index fitted the data acceptably well (Figure 9), but all encountered convergence problems at MPD. The CPUE-only model runs contained little information on the upper bound to B_0 (Table 9).

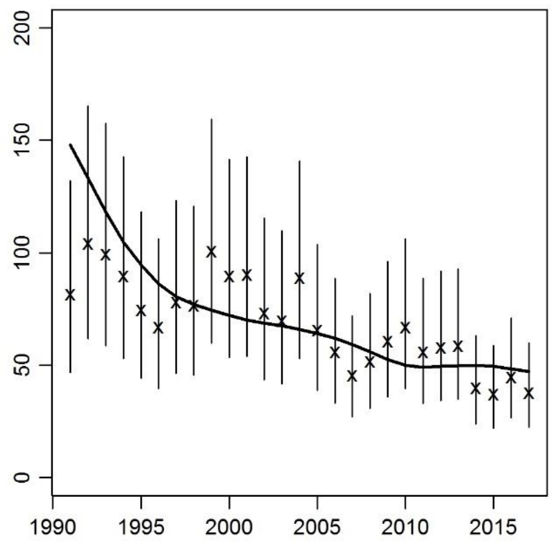

Figure 9: Hake HAK 1 fit (line) to the CPUE biomass index (points, with 95% CI), for the model run where CPUE was included and research trawl survey biomass series excluded.

Table 9: MCMC estimates of quantities for hake HAK 1 model runs assuming different priors for year class strength (σ_R) and with either research trawl or CPUE as the biomass index. CPUE sensitivity runs assumed an additional process error (PE) of either 0.15 or 0.25.

Biomas index	Research trawl	Research trawl	CPUE (PE=0.15)	CPUE (PE=0.25)
Prior σ_R	1.1	0.7	1.1	1.1
				Posterior estimates
B_0	54.6 (41.5–83.2)	52.6 (41.7–80.1)	254.9 (61.1–584.9)	258.2 (59.8–580.2)
% B_0	49 (34–67)	53 (38–70)	58 (47–69)	62 (48–75)
M	0.19 (0.16–0.22)	0.18 (0.16–0.21)	0.23 (0.19–0.25)	0.23 (0.20–0.26)
σ_R	0.79 (0.63–0.98)	0.62 (0.51–0.75)	0.81 (0.66–1.03)	0.81 (0.64–1.00)

3.2.5 Other sensitivity runs

Other sensitivity models were also run, but are not reported in detail here (some examples are given in Table 10). These included investigating sensitivity of the model estimates to assumptions on fishery and research vessel selectivities, data weighting, assumed prior on the trawl survey catchability, assumed annual cycle (order of processes and length of time steps), and the assumed prior on *M*. Some sensitivity runs had negligible impact on model outcome (e.g., *M* prior), or produced predictable results (e.g., mean of survey *q* prior). Changing some model assumptions, e.g., selectivities, was found to influence the outcome (B_0, %B_0) with little change in fits to the observations. Because *M* was estimated in the model, a logistic ogive on at least one data set (here the fishery) was assumed to reduce the effect of *M* and selectivity being confounded.

Table 10: Hake HAK 1 assessment model sensitivity runs, with model assumptions in the upper part of the table, and estimates and likelihoods in the lower part.

M-at-age	Constant	Constant	Constant	Constant	Constant	Constant
Fishery selectivity	Logistic	Double normal	Logistic	Logistic	Logistic	Logistic
Research trawl selectivity	Double normal	Logistic	Double normal	Double normal	Double normal	Double normal
Weight on fishery prop.-at-age	Base	Base	Halved	Base	Base	Base
Mean of RV *q* prior	Base	Base	Base	Halved	Doubled	Base
YCS prior σ_R	1.1	1.1	1.1	1.1	1.1	0.7
						Estimates
M	0.2	0.21	0.19	0.21	0.18	0.18
B_0	55 000	69 860	56 648	73 144	48 654	52 922
% B_0	44.7	48.1	45.7	48.4	42.6	51.3
VB/SSB$_{2000}$	100	87	100	100	100	100
						Likelihoods
Tangaroa Nov-Dec biomass	-14.20	-14.19	.14.11	-14.40	-14.14	-14.64
Tangaroa Nov-Dec prop.-at-age	385.14	385.55	380.92	384.61	385.79	387.18
Fishery prop.-at-age	398.10	395.76	273.20	398.38	397.85	397.98

3.3 Final model runs

The final model run was as described in Section 4.1.1, with the main changes from the assumptions of the previous assessment (Horn 2015) being the estimation of a constant *M*-at-age with informed prior (previously U-shaped), logistic fishery selectivity (previously double normal), an assumed year class strength σ_R of 0.7 or 1.1 (base model now assumes 0.7; previously 1.1), and the exclusion of a sensitivity run using CPUE. MCMC estimation was used for all final models. All MCMC analyses were considered acceptable by the Fisheries New Zealand Working Group (example diagnostics are given in Appendix A).

The fits of the base model to the research trawl biomass indices were acceptable, although the model did not capture the declining trend in the November-December series since 2008, nor the decline-then-increase trend in the April surveys (Figures 10 and 11). The fits to the commercial fishery proportions-at-age were generally good, but some proportions-at-age were under- and then over-estimated by the model (i.e., over-estimation of incoming cohorts, e.g., in 1998, 2008, 2017) (Figures 12, 13). There was no visual difference in the fits to the fishery proportions-at-age in the runs assuming σ_R of 0.7 or 1.1. The fits to the research trawl survey proportions at age were generally good, although in contrast to the fit to the fishery proportions at age, there was a tendency to over-estimate incoming cohorts in the early years of the November-December survey, and under-estimate them in later years (Figures 14, 15 and 16). The relatively strong recruitment from around 1992 apparent in the fishery proportions-at-age samples was not well fitted; this recruitment was not apparent in the research survey samples.

Year class strength estimates suggested that the stock was characterised by a group of above average year class strengths in the late 1970s, a very strong year class in 1980, followed by a period of average to less than average recruitment through to 2014 (Figure 17).

The absolute catchability of the research trawl surveys was estimated to be extremely low, implying a larger stock than expected (Figure 18). Although catchability was expected to be higher, hake are believed to be relatively more abundant over rough ground (that is likely to be avoided during a trawl survey), and it is reported that hake can school off the bottom, particularly during their spring–summer spawning season, hence reducing their availability to the bottom trawl (Fisheries New Zealand Working Group).

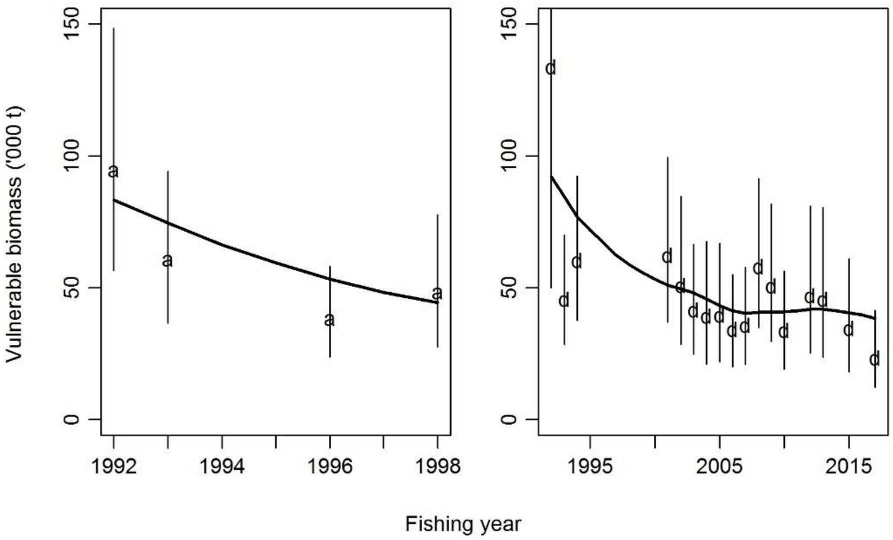

Figure 10: MPD fits of the base model for the hake HAK 1 stock (solid lines) to the April-May (a) and November-December (d) research trawl biomass indices. Vertical lines indicate the 95% CI.

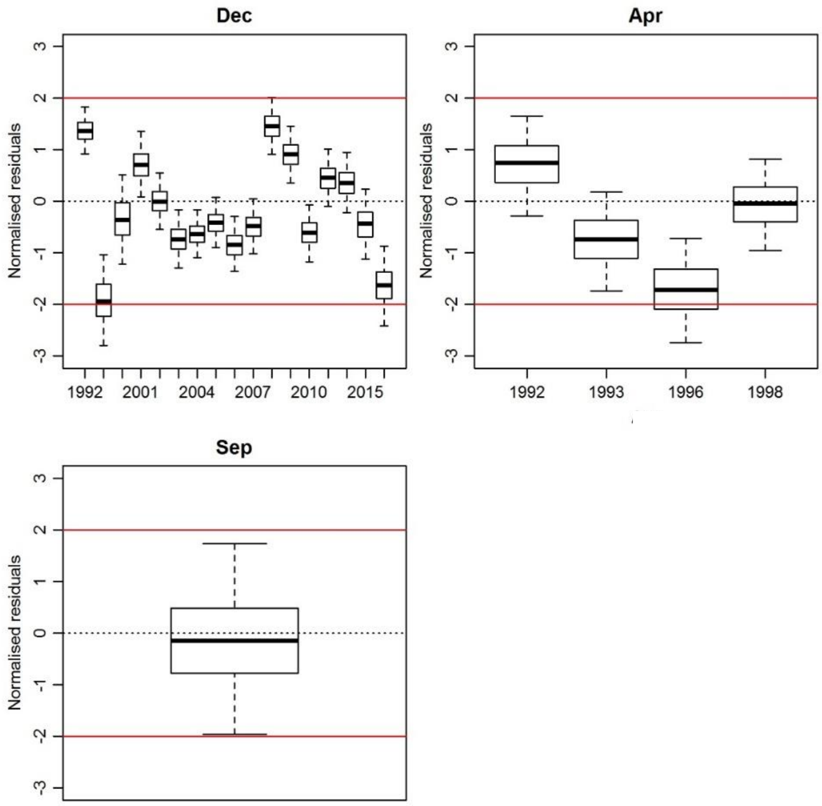

Figure 11: MCMC implied residuals of the base model for the hake HAK 1 stock for the April-May (Apr), November-December (Dec), and September (Sep) research trawl biomass indices. Box plots show the median, inter-quartile range, and 95% CI.

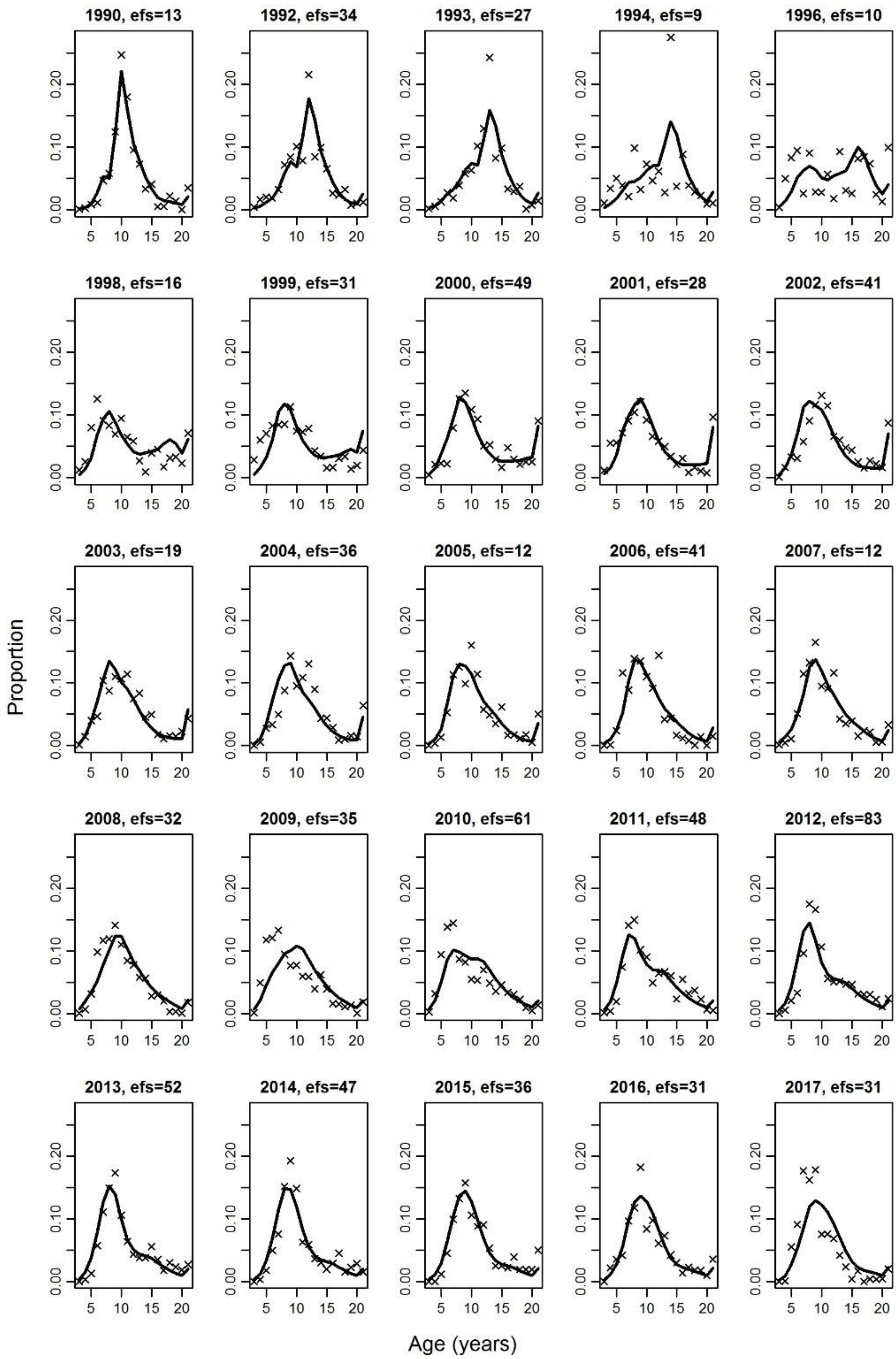

Figure 12: Hake HAK 1 base model MPD fit (solid lines) to the proportion-at-age observations from the Fisheries New Zealand observer commercial fishery samples (×). efs, multinomial effective sample size.

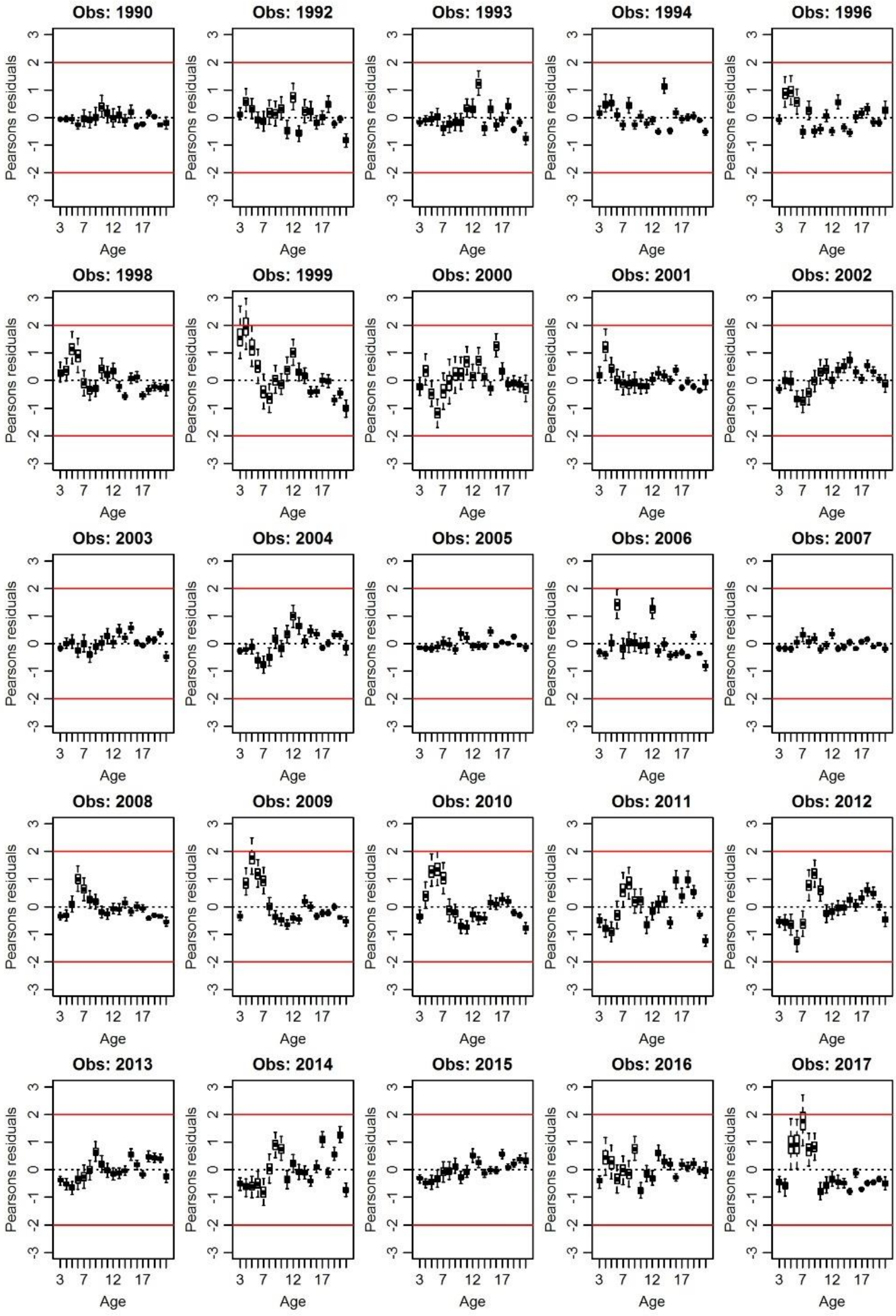

Figure 13: Hake HAK 1 base model MCMC implied residuals for the proportion-at-age observations from the Fisheries New Zealand observer commercial fishery samples (×). efs, multinomial effective sample size.

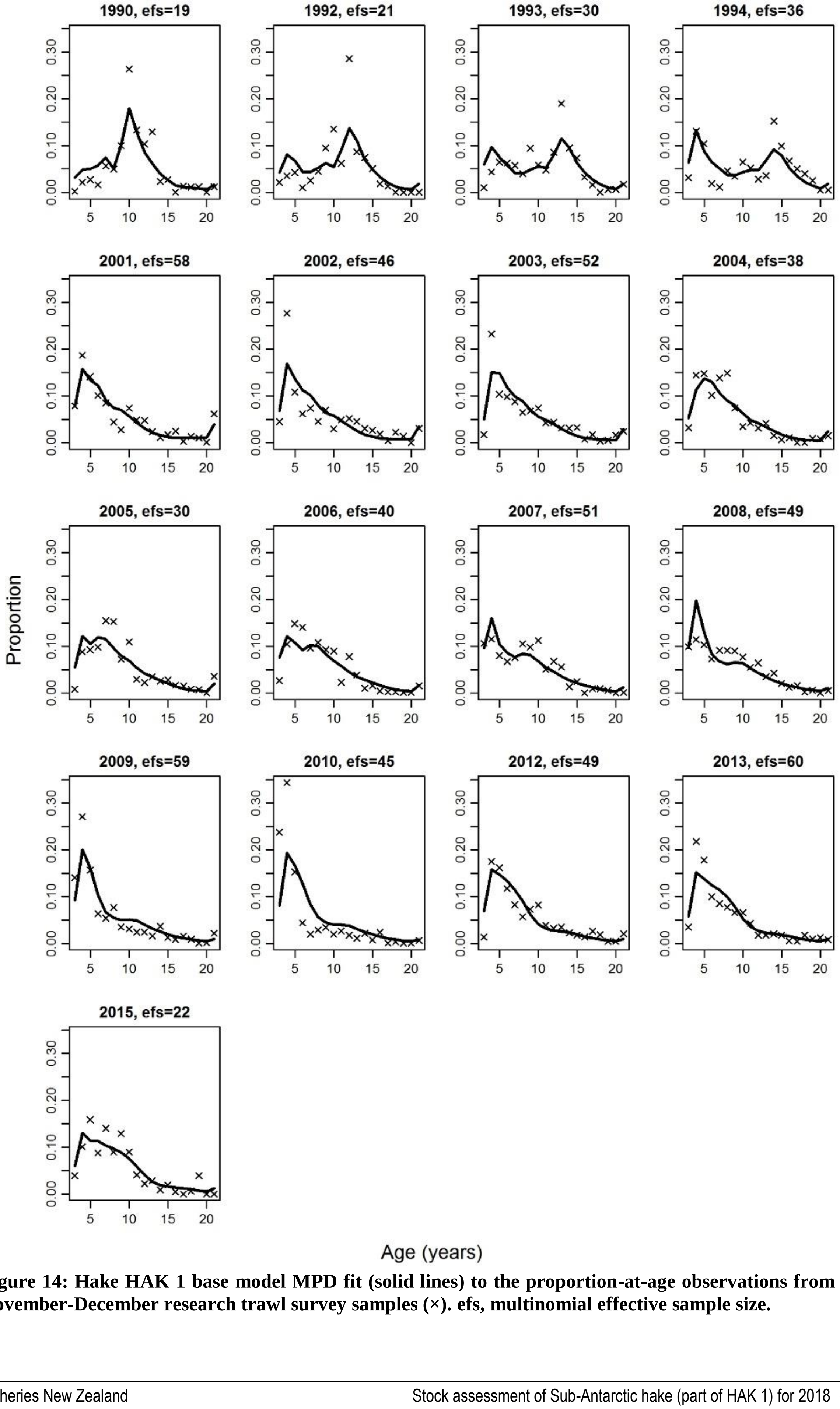

Figure 14: Hake HAK 1 base model MPD fit (solid lines) to the proportion-at-age observations from the November-December research trawl survey samples (×). efs, multinomial effective sample size.

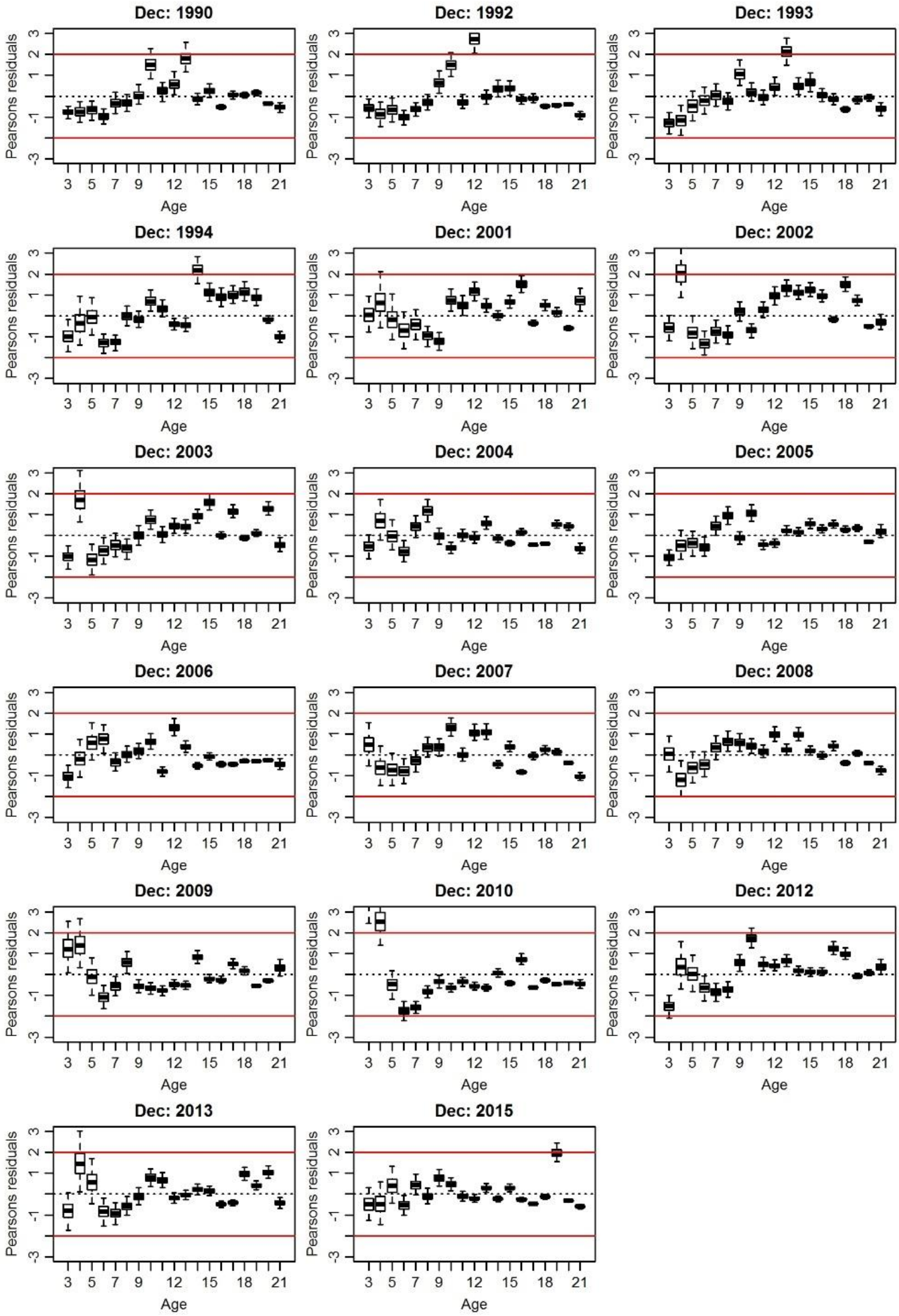

Figure 15: Hake HAK 1 base model MCMC implied residuals for the proportion-at-age observations from the November-December research trawl survey samples (×). efs, multinomial effective sample size.

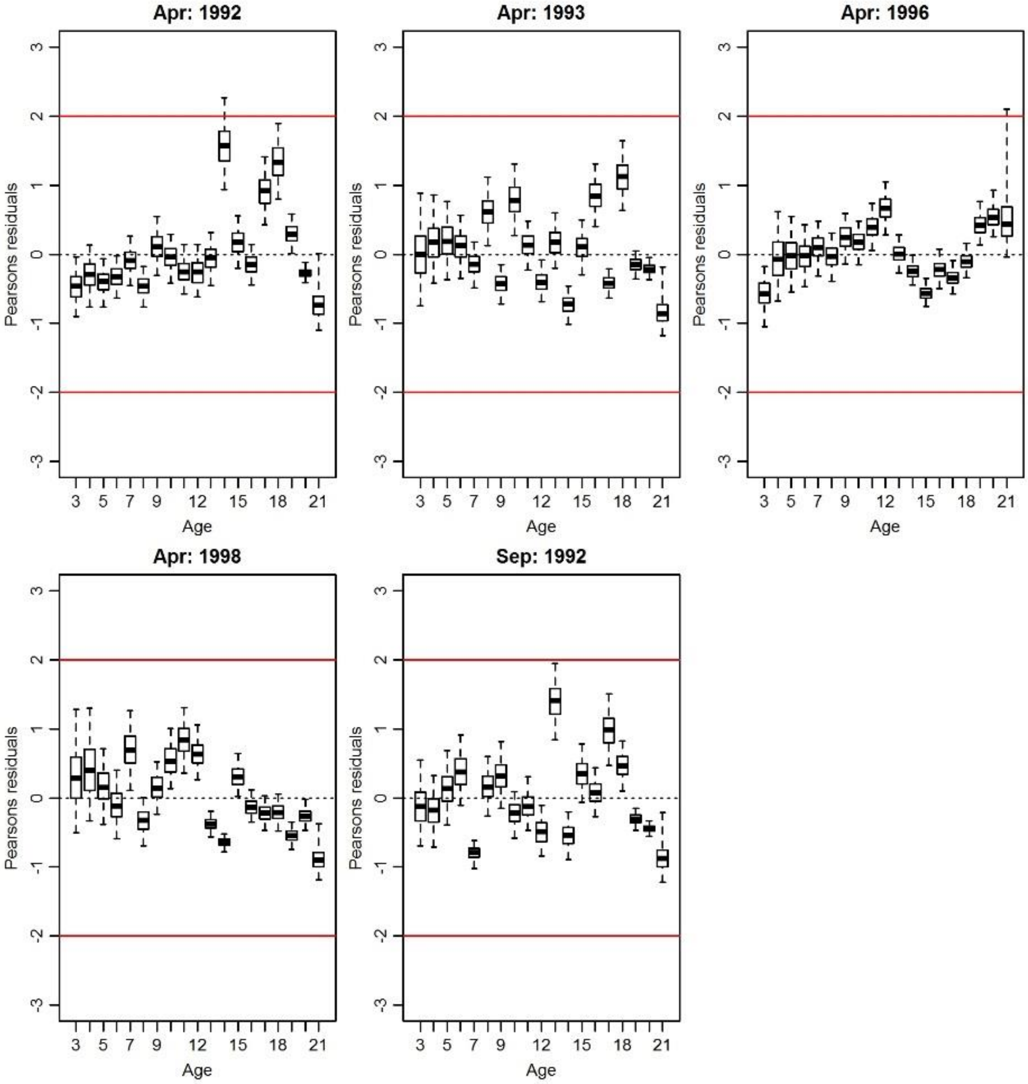

Figure 16: Hake HAK 1 base model MCMC implied residuals for the proportion-at-age observations from the April-May and September research trawl survey samples (×). efs, multinomial effective sample size.

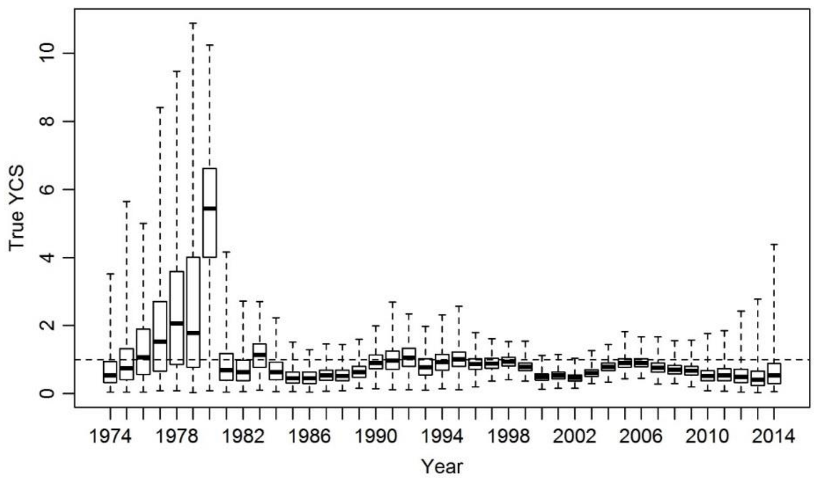

Figure 17: Estimated posterior distributions of year class strengths for the base case hake HAK 1 stock. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

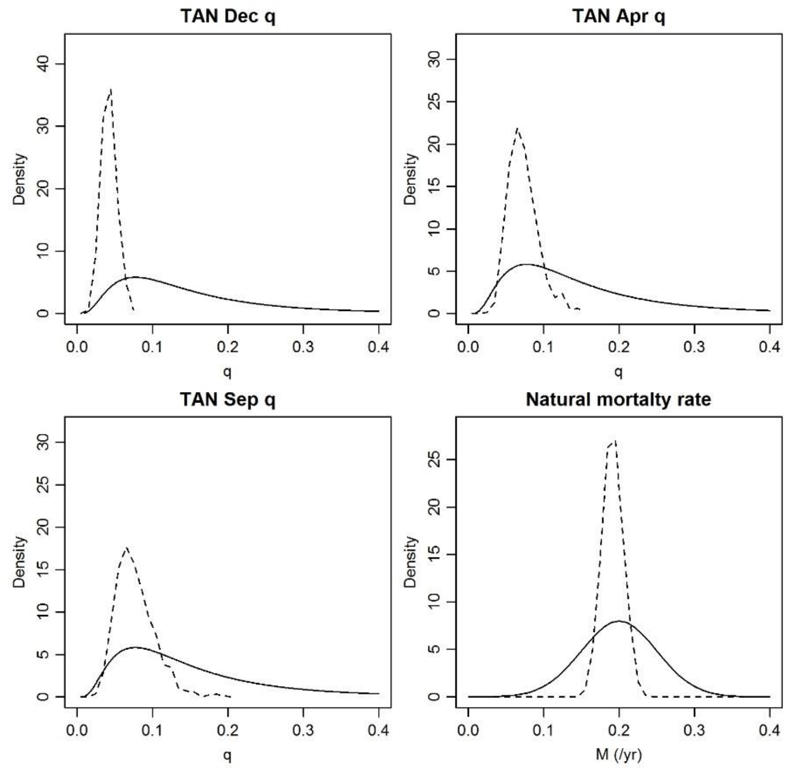

Figure 18: Estimated prior (solid lines) and posterior distributions (broken line) of catchability for the research trawl surveys, and natural mortality rate, for the base case hake HAK 1 stock model.

Estimated selectivities for the research trawl surveys were not strongly domed, even though they were estimated using double-normal parameterisation (Figure 19). Hake were fully selected by the November-December survey at age 4.5, by the April-May and September surveys at age 15, and by the fishery at about age 10. No hypothesis was presented during the Fisheries New Zealand Working Group meetings for why the selectivities in the November-December, and April-May and September surveys, were estimated to have been so different.

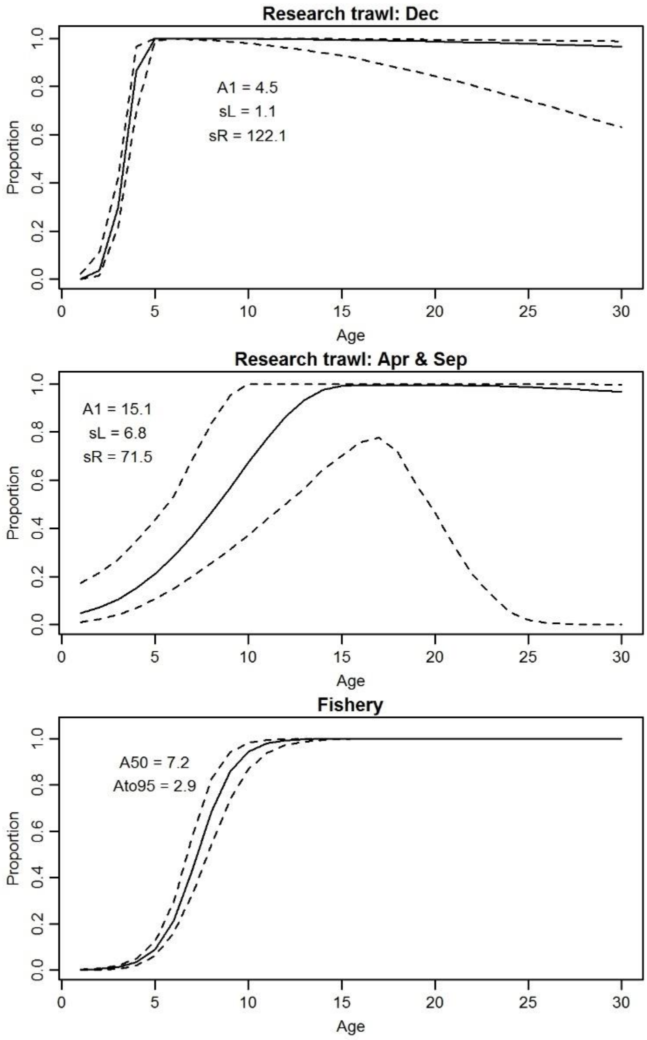

Figure 19: Estimated selectivities for the base case hake HAK 1 stock model.

Biomass estimates for the stock appear relatively healthy, with estimated current biomass from the base model at about 55% of B_0 (Figure 20, Table 11). Despite changes in the assumptions between the 2015 and 2018 assessments, the biomass estimates from the base model and previous model (run Previous) were similar (Table 11). The MPD model runs were found to be sensitive to the assumed prior on year class strengths (σ_R), but modifying σ_R to 0.7 assumption made little difference to MCMC results (run Base 0.7).

Table 11: Bayesian median (95% credible intervals) (MCMC) of B_0, B_{2018}, B_{2018} as a percentage of B_0 ,and the probability of B_{2018} being below the target (40% B_0), for the hake HAK 1 base model and sensitivity runs.

Model run	B_0	B_{2018}	B_{2018} (%B_0)	P(B_{2018} < 0.4 B_0)
Base	54 600 (41 500–83 200)	27 200 (14 800–51 300)	49 (34–67)	0.11
Previous	54 400 (40 100–85 400)	31 700 (16 900–61 200)	57 (40–78)	0.03
Base 0.7	52 600 (41 700–80 100)	27 900 (16 100–52 100)	53 (38–70)	0.05

Annual exploitation rates (catch over vulnerable biomass) were low in all years as a consequence of the high estimated stock size relative to the level of catches (Figure 21). A depletion plot showed that the hake stock was estimated never to have been overfished, and that overfishing had never taken place (Figure 22).

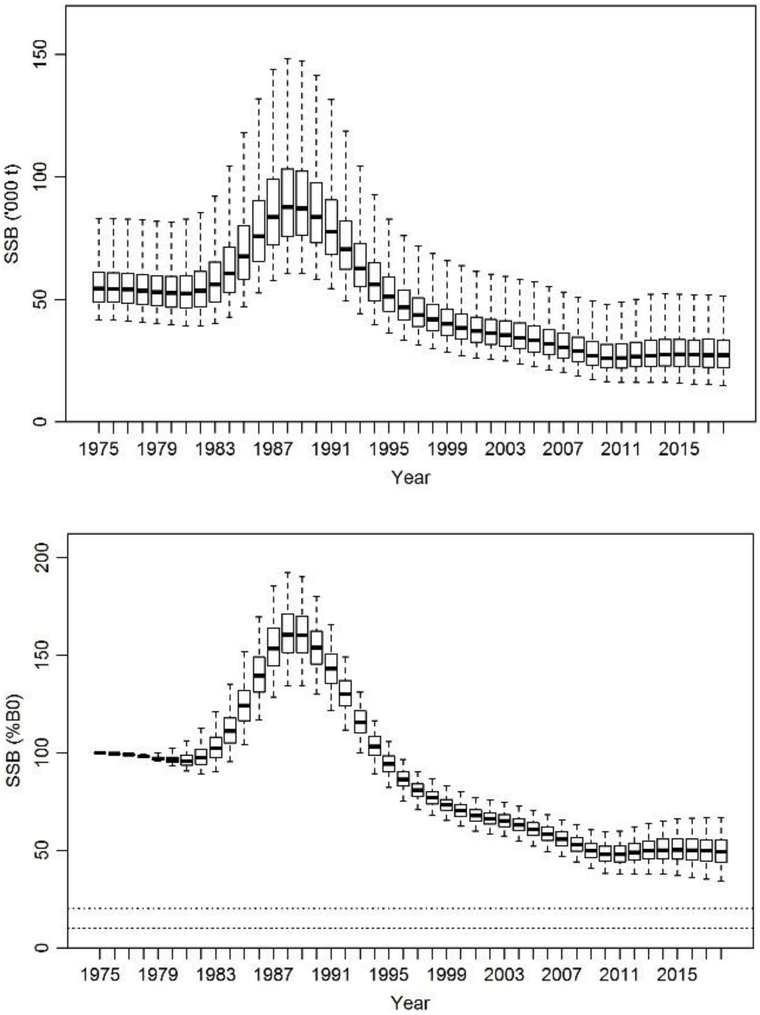

Figure 20: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the hake HAK 1 base case model for absolute biomass and biomass as a percentage of B_0. The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown on the bottom panel.

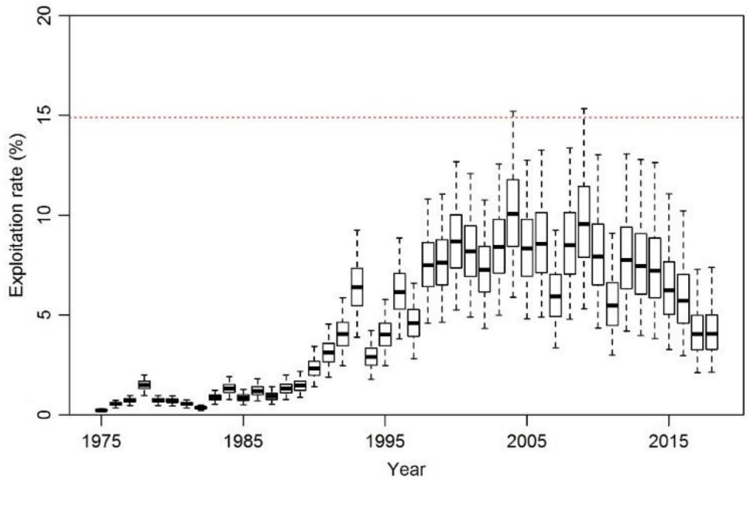

Figure 21: Exploitation rates (catch over vulnerable biomass) for the hake HAK 1 base case model. The horizontal broken line indicates the exploitation rate at 40% B_0 (U_{40}; median derived from MCMC samples).

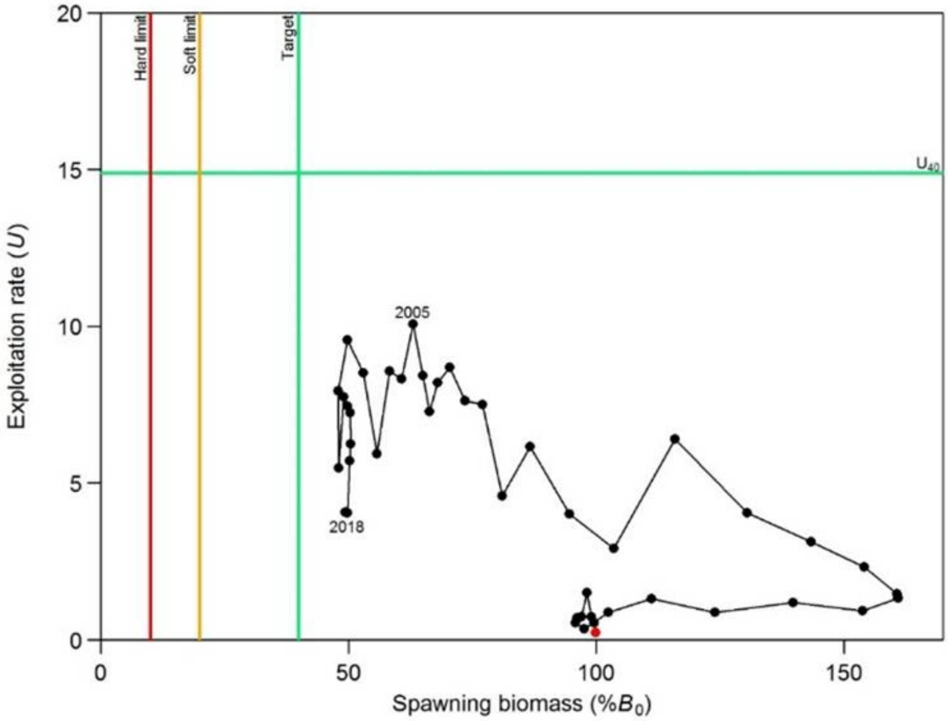

Figure 22: Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the hake HAK 1 stock base model from the start of the assessment period in 1974 (represented by a red point), to 2018. The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the % B_0 target (40% B_0) and the corresponding exploitation rate (U_{40}). Biomass and exploitation rate estimates are medians from MCMC results.

Biomass projections to 2023 were made for the Base model run assuming future catches in the Sub-Antarctic to be an average of the catch from the last three years (1366 t), or the TACC (3701 t) (Table 12). For each projection scenario, future recruitment variability was sampled from actual estimates between 1974 and 2012 (entire time series), or 2003 and 2012 (last ten years).

At the current catch (1366 t), SSB was predicted to remain stable. At a catch of the TACC (3701 t), SSB was predicted to decrease. At the current catch, the estimated probability of SSB going below the soft or hard limits was zero. At the TACC level of catch, the probability of the SSB dropping below the soft limit was 5% if large year classes such as those seen around 1980 were possible, and 12% if year class strength remained at recent levels.

Table 12: HAK 1 Bayesian median and 95% credible intervals (in parentheses) of projected B_{2023}, B_{2023} as a percentage of B_0, and B_{2023}/B_{2018} (%) for the model runs.

Model run	Catch	B_{2023}	B_{2023} (%B_0)	B_{2023}/B_{2018} (%)	p(B_{2023} < 0.2 B_0)	p(B_{2023} < 0.1 B_0)
Base 1974–2012	1 366	28 800 (14 500–59 500)	52 (33–81)	104 (76–154)	0	0
	3 701	21 000 (7 000–51 800)	38 (16–71)	76 (40–131)	0.05	0.01
Base 2003–2012	1 366	26 200 (13 300–53 200)	47 (30–72)	95 (73–130)	0	0
	3 701	18 400 (5 600–46 100)	33 (12–61)	67 (34–103)	0.12	0.01

4. DISCUSSION

The 2018 assessment of hake in the Sub-Antarctic estimated that the stock was not overfished, and that overfishing had never taken place.

Both the trawl survey and CPUE indices suggest that biomass declined more over the last two decades than was estimated by the model, however, the year class strengths influence how well the biomass indices can be fitted. It would be useful to investigate the estimation of year class strengths further, including the residual patterns in the fits to proportions-at-age. This might include allowing fishery selectivity, and possibly trawl survey selectivity, to change over time.

It was unclear how accurate the research trawl survey biomass index was when estimates were based upon relatively small catches (fewer than 100 fish). In this respect, the estimated low q for the research trawl survey was also a little concerning, and independent evidence for accepting such a low q would increase confidence in the assessment.

The presence of exceptionally large cohorts at the start of the fishery seems to be a signal from the data, but whether such an event was genuine, and could occur again, is currently unknown. Such large year classes have now not been observed for more than thirty years. For projections it would be precautionary to assume that such large recruitments will not occur in the future.

5. MANAGEMENT IMPLICATIONS

The assessment was accepted by the Fisheries New Zealand Working Group. The stock was predicted to be larger than the target biomass depletion level. At the current catch the stock was likely to remain at a similar size, whereas if catches increased to the TACC the stock may decline.

6. ACKNOWLEDGMENTS

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APPENDIX A

Examples of the diagnostics for the MCMC runs are shown here. MCMC results were considered acceptable if the key quantities of interest (e.g., B_0, $\%B_0$, M) from three independent chains were not materially different (Figure A1), and the chains did not drift or suggest that the parameter space was not being fully investigated (Figure A2).

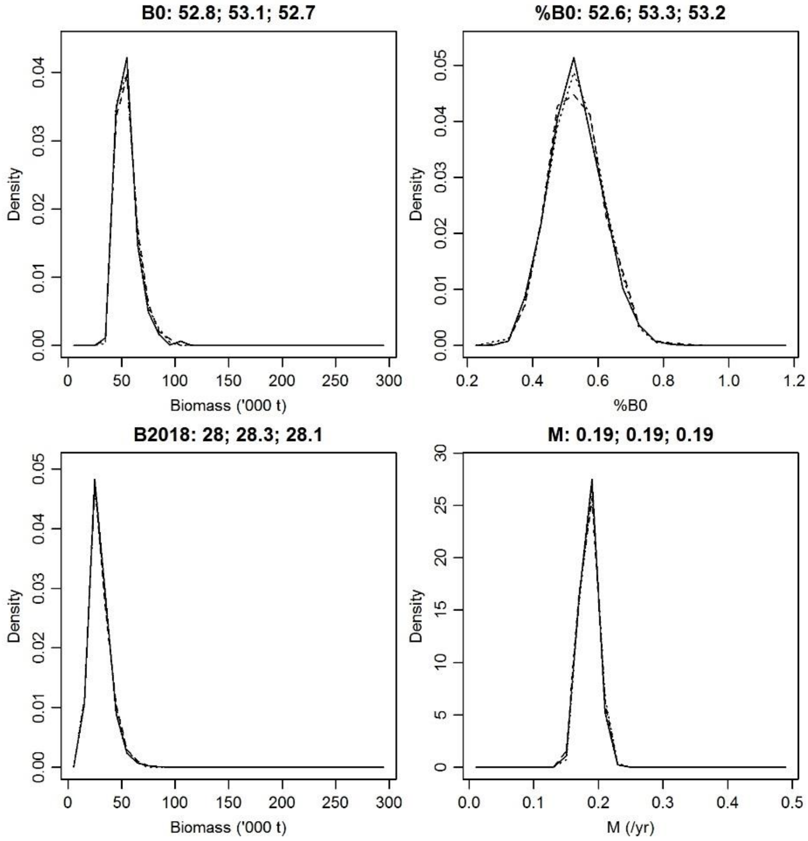

Figure A1: Joint posterior estimates of B_0, $\%B_0$, B_{2018} and M, from 3000 samples from the three MCMC chains (1000 from each chain), for the Base model run. Title gives the median quantity from each chain (biomass in '000 t).

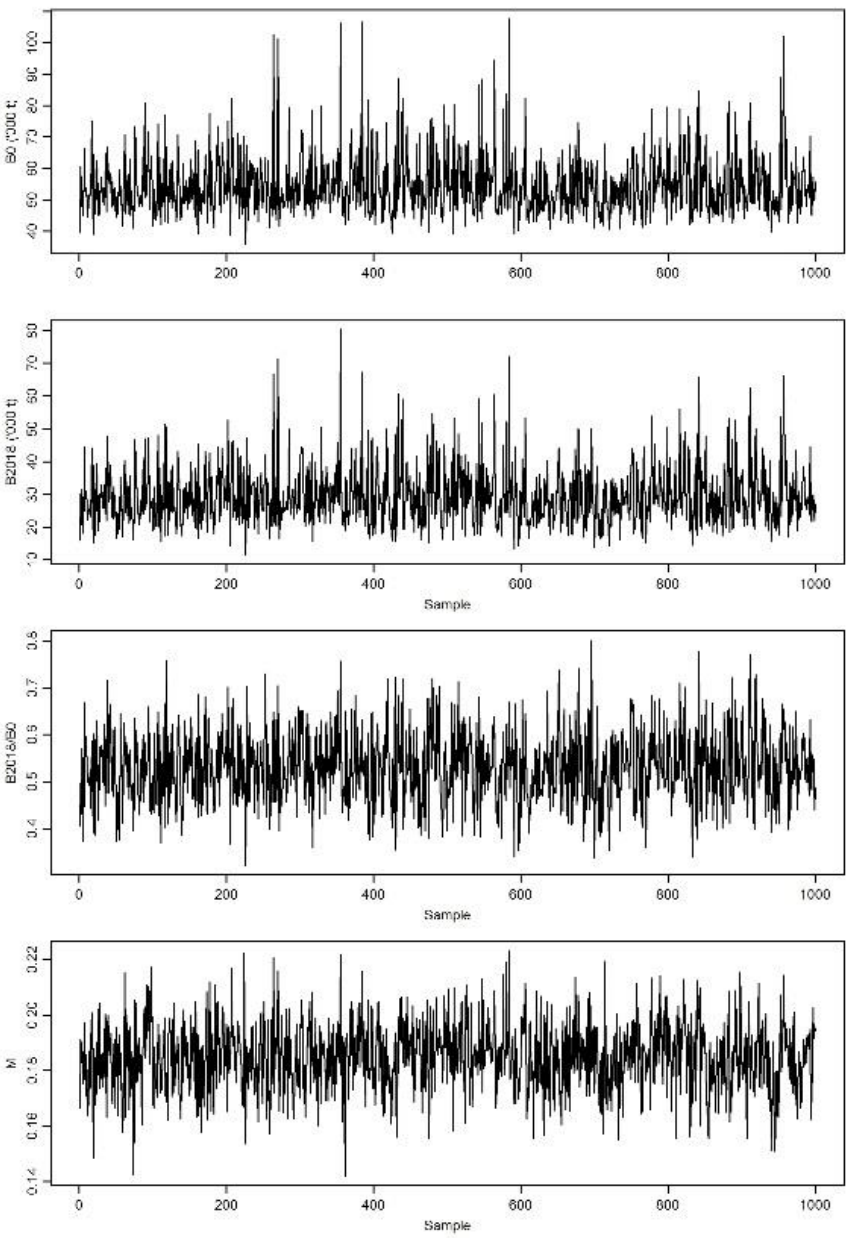

Figure A2: Example MCMC single chain, paramater and quantity estimates, for the Base model.