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Stock assessment of hake (*Merluccius australis*) in the Sub-Antarctic (HAK 1) for the 2023–24 fishing year

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PLAIN LANGUAGE SUMMARY

This report summarises the stock assessment of hake in the Sub-Antarctic in HAK 1 for the 2023–24 fishing year. The main index of abundance was the summer Sub-Antarctic trawl survey. Initial spawning stock biomass was estimated as 72 600 t (95% credible intervals 60 200–93 800 t) with current status of 65% B_0 (95% credible intervals 52–79% B_0). Three-year projections showed that biomass is expected to either stay the same or decrease slightly over the next three years under assumptions of both current catch and a catch equal to the HAK 1 TACC and recent recruitment. With long term average recruitment, the status is expected to increase under both catch scenarios.

EXECUTIVE SUMMARY

Dunn, A.[1]; Mormede, S.[2]; Webber, D.N.[3] (2026). Stock assessment of hake (*Merluccius australis*) in the Sub-Antarctic (HAK 1) for the 2023–24 fishing year.

***New Zealand Fisheries Assessment Report 2026/02*. 48 p.**

Hake (*Merluccius australis*) is an important commercially caught species found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) south of 40° S and caught mainly by deepwater demersal trawls. Hake are managed in three Fishstocks: (i) the Challenger Fisheries Management Area (FMA) (HAK 7), (ii) the Chatham Rise FMA (HAK 4), and (iii) the remainder of the EEZ comprising the Auckland, Central, Southeast (Coast), Southland, and Sub-Antarctic FMAs (HAK 1). Hake are assessed as three main biological stocks: the west coast, Chatham Rise, and Sub-Antarctic.

This report provides a stock assessment of the Sub-Antarctic stock (hake in HAK 1) up to the end of the 2023–24 fishing year. The assessment was implemented using Casal2, updating the previous CASAL-based model with new observations since the last assessment, including revised survey biomass indices and sex-based age composition data from both surveys and commercial fisheries. The primary indices of abundance were the Sub-Antarctic *Tangaroa* trawl survey series (November-December and April-May), along with associated age frequency data.

The median of the posterior distribution of initial biomass was 72 600 t (95% credible intervals 60 200–93 800 t) with current status of 65% B_0 (95% credible intervals 52–79% B_0) and current biomass of 47 000 t (95% C.I.s 33 200–70 400 t). Markov chain Monte Carlo (MCMC) iterations showed no evidence of non-convergence and diagnostics of the model fits were reasonable.

Assessment model sensitivity analyses did not suggest that alternative assumptions would lead to significantly different estimates of current status, though the model remained sensitive to assumptions about recent and future year class strengths. Model projections suggested that the biomass of hake in the Sub-Antarctic would remain stable or increase slightly under current catch levels (approximately 1084 t annually) and would decline slowly toward the target biomass of 40% B_0 over the next three years if catches were at the level of the total allowable commercial catch (3701 t) and recent lower recruitment levels continued.

The stock assessment found that the stock is currently well above all management reference points, with virtually no risk of falling below the target (40% B_0) under any projected scenario over the next three years.

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1. INTRODUCTION

Hake (*Merluccius australis*) is an important commercially caught species found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) south of 40° S, typically in depths of 250–800 m (Hurst et al. 2000). Hake are caught mainly by deepwater demersal trawls, usually as bycatch in hoki (*Macruronus novaezelandiae*) target fisheries, and with some caught by direct targeting (Dunn et al. 2021a).

The current management of hake divides the fishery into three Fishstocks: (i) the Challenger Fisheries Management Area (FMA) (HAK 7), (ii) the Chatham Rise FMA (HAK 4), and (iii) the remainder of the EEZ comprising the Auckland, Central, Southeast (Coast), Southland, and Sub-Antarctic FMAs (HAK 1). An administrative Fishstock (with no recorded landings) is also defined for the Kermadec FMA (HAK 10) (Fisheries New Zealand 2024). There are likely to be three main biological stocks of hake. These are the west coast of the South Island (HAK 7), the Chatham Rise (HAK 4 and the northern regions in HAK 1), and the Sub-Antarctic (HAK 1) (Fisheries New Zealand 2024). The Quota Management Areas (QMA) for hake and stock boundaries are shown in Figure 1.

Previous analyses showed that the length frequencies of west coast hake were different to both the Chatham Rise and the Sub-Antarctic. The growth parameters were also different among the three areas (Horn 1997) and juvenile hake are found in all three areas (Hurst et al. 2000). Analysis of morphometric data from the 1990s (Colman, NIWA, unpublished data) showed little difference between hake on the Chatham Rise and those on the east coast of the North Island, but significant differences between Chatham Rise hake and those from the Sub-Antarctic, Puysegur, and on the west coast of the South Island. Hake in Puysegur were morphometrically similar to Sub-Antarctic hake and may be different from the Sub-Antarctic hake. Hence, the stock affinity of hake from Puysegur was considered to be uncertain (Fisheries New Zealand 2024).

Hake stocks have previously been assessed with stock assessments for at least one of the three stocks each year since 1991. Previous assessments of hake were in the 1991–92 (Colman et al. 1991), 1992–93 (Colman & Vignaux 1992), 1997–98 (Colman 1997), 1998–99 (Dunn 1998), 1999–2000 (Dunn et al. 2000), 2000–01 (Dunn 2001), 2002–03 (Dunn 2003a), 2003–04 (Dunn 2004), 2004–05 (Dunn et al. 2006), 2005–06 (Dunn 2006), 2006–07 (Horn & Dunn 2007), 2007–08 (Horn 2008), 2009–10 (Horn & Francis 2010), 2010–11 (Horn 2011), 2011–12 (Horn 2013a), 2012–13 (Horn 2013b), 2014–15 (Horn 2015), 2016–17 (Horn 2017), 2017–18 (Dunn 2019), 2018–19 (Kienzle et al. 2019), 2019–20 (Holmes 2021), 2020–21 fishing years (Dunn et al. 2021b), 2022–23 (Dunn et al. 2023a), and 2023–24 (Dunn 2024). The most recent stock assessment for Sub-Antarctic hake was for the 2020–21 fishing year (Dunn et al. 2021b).

The previous Sub-Antarctic hake stock assessment (Dunn et al. 2021b) was implemented as sex-specific integrated statistical catch-at-age model using commercial catch-at-age frequency, catch per unit effort (CPUE), resource survey biomass, and survey age frequency observations using CASAL (Bull et al. 2012). The most recent characterisation of the fishery and CPUE indices were updated by Dunn et al. (2025) including data up to the end of the 2023–24 fishing year.

The main indices of abundance provided to the model were the Sub-Antarctic summer and autumn trawl surveys and associated age composition data. The biomass indices provided the most information to the model. The median of the posterior distribution of initial biomass was 72 600 t (95% credible intervals 60 200–93 800 t) with current status of 65% B_0 (95% credible intervals 52–79% B_0). Assessment model sensitivity analyses did not suggest that alternative assumptions would lead to a significantly different outcome. The model projections at the level of then current catch suggested that the biomass of hake in the Sub-Antarctic would remain relatively stable, and only projections with recent (lower) year class strengths at a catch level of the Total Allowable Commercial Catch for HAK 1 would result in a decline, albeit slowly, towards the target biomass of 40% B_0.

This report fulfils Specific Objective 2 of Project HAK2024-01. The overall Objective was “To carry out stock assessments of hake (*Merluccius australis*) on the Sub-Antarctic (HAK 1) including estimating stock biomass and stock status” and Specific Objective 2 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.”. This report updates the Sub-Antarctic stock assessment with the most recent available data up to the end of the 2023–24 (2024) fishing year. The catch history, resource survey indices, revised cage compositions, and CPUE indices are described by Dunn et al. (2025).

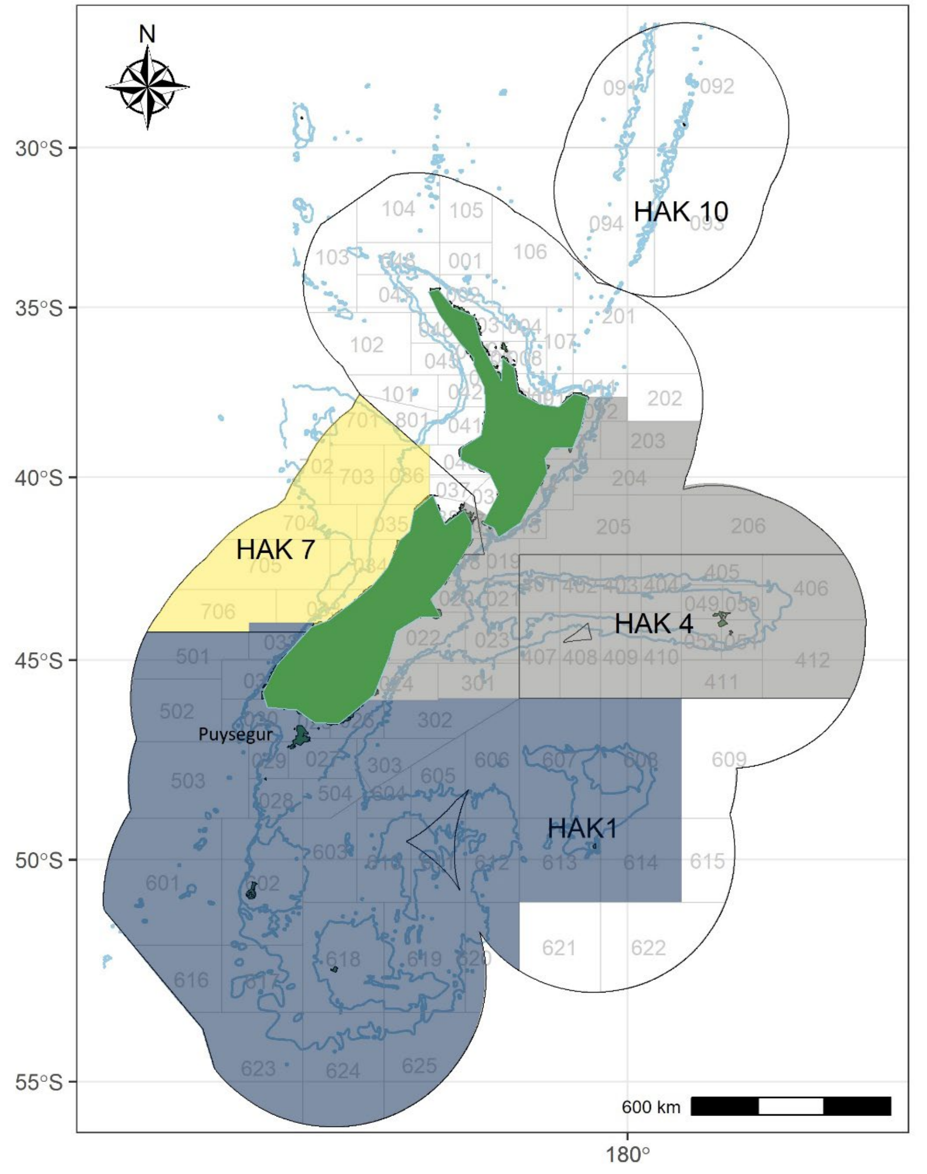

Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, and 10 (black lines), statistical areas (grey), and hake biological stock boundaries: Sub-Antarctic (yellow), Chatham Rise (light grey), and Sub-Antarctic (dark grey).

2. METHODS

2.1. Data available for the assessment

2.1.1 Catch history

In the late 1990s and early 2000, fishers were found to have misreported hake catches between Quota Management Areas (QMAs) (Fisheries New Zealand 2024). The reported catches of hake in each area were reviewed in 2002 and likely misreported records identified by Dunn (2003b), who then provided revised estimates of the total landings by stock. Almost all the area misreporting was from HAK 7 (WCSI) to the Chatham Rise (HAK 4 and the part of HAK 1 on the Chatham Rise), with only a small amount to the Sub-Antarctic area of HAK 1 (Dunn 2003b). Dunn (2003b) estimated that the level of hake over-reporting on the Chatham Rise (and hence under-reporting on the west coast South Island) was between 16 and 23% (700–1000 t annually) of landings between 1994–95 and 2000–01, mainly in June, July, and September. Probable levels of area misreporting prior to 1994–95 and between the Sub-Antarctic and the west coast South Island were estimated as low (Dunn 2003b). There was no evidence of similar area misreporting since 2001–02 (Ballara 2018).

Because a substantial proportion of hake catch was taken in September of the early years (Figure 2) when catch and effort data were available for the fishery (1990–1994) and was more likely to be similar in characteristics to the catch taken in October–December (the period of the year when more than three quarters of the catch was taken), catch from September was assigned to the following fishing year. A revised catch history for hake, accounting for this misreporting, and also with the September catch allocated to the following fishing year (and labelled model year, September to August, in this report), for the Sub-Antarctic is given in Table 1 and shown in Figure 3. The total catch for 2024–25 was not known at the time of writing this report and was assumed to be equal to the average catch reported over the most recent five years.

Table 1: Total (scaled) catches (t) by stock for hake from 1990 to 2020 for the September–August model year (where 1990 is 1 September 1989–31 August 1990), split into the summer (Sep-Mar) and winter (Apr-Aug) fisheries.

Year	Summer	Winter	Year	Summer	Winter	Year	Summer	Winter
1975	113.6	6.4	1992	2 653.4	152.7	2009	2 423.1	22.2
1976	266.1	14.9	1993	3 807.8	110.7	2010	1 882.2	44.6
1977	352.2	19.8	1994	1 569.7	50.1	2011	1 292.6	26.0
1978	721.5	40.5	1995	1 913.5	68.6	2012	1 855.2	46.6
1979	344.7	19.3	1996	2 717.6	71.8	2013	1 842.7	35.5
1980	331.4	18.6	1997	1 868.5	50.4	2014	1 794.3	45.9
1981	257.6	14.4	1998	2 838.1	105.5	2015	1 565.8	42.5
1982	169.5	9.5	1999	2 639.6	231.6	2016	1 459.2	10.8
1983	424.2	23.8	2000	2 879.7	219.9	2017	912.7	31.3
1984	683.7	38.3	2001	2 684.1	132.3	2018	1 140.7	9.3
1985	497.1	27.9	2002	2 320.1	123.7	2019	640.2	6.8
1986	774.6	43.4	2003	2 661.7	118.1	2020	881.1	15.9
1987	675.1	37.9	2004	3 205.0	22.9	2021	1 281.5	14.5
1988	1 036.9	58.1	2005	2 550.9	39.7	2022	1 519.6	4.4
1989	1 171.3	65.7	2006	2 511.2	27.0	2023	933.5	15.5
1990	554.7	163.8	2007	1 689.9	16.5	2024	750.6	2.4
1991	2 154.6	163.8	2008	2 313.6	16.4	2025[1]	1 073.2	10.6

1. Assumed catch based on the mean of the previous 5 years.

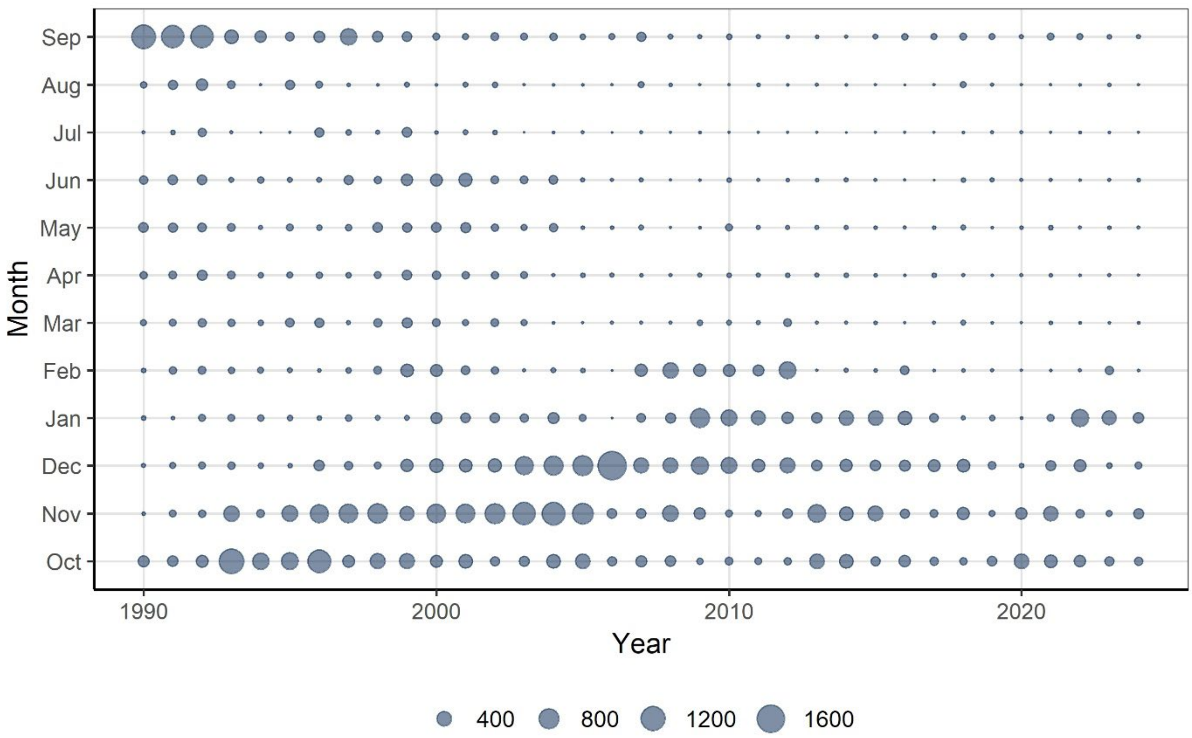

Figure 2: Relative catch of hake (t) on the Sub-Antarctic by month and calendar year, 1990–2024.

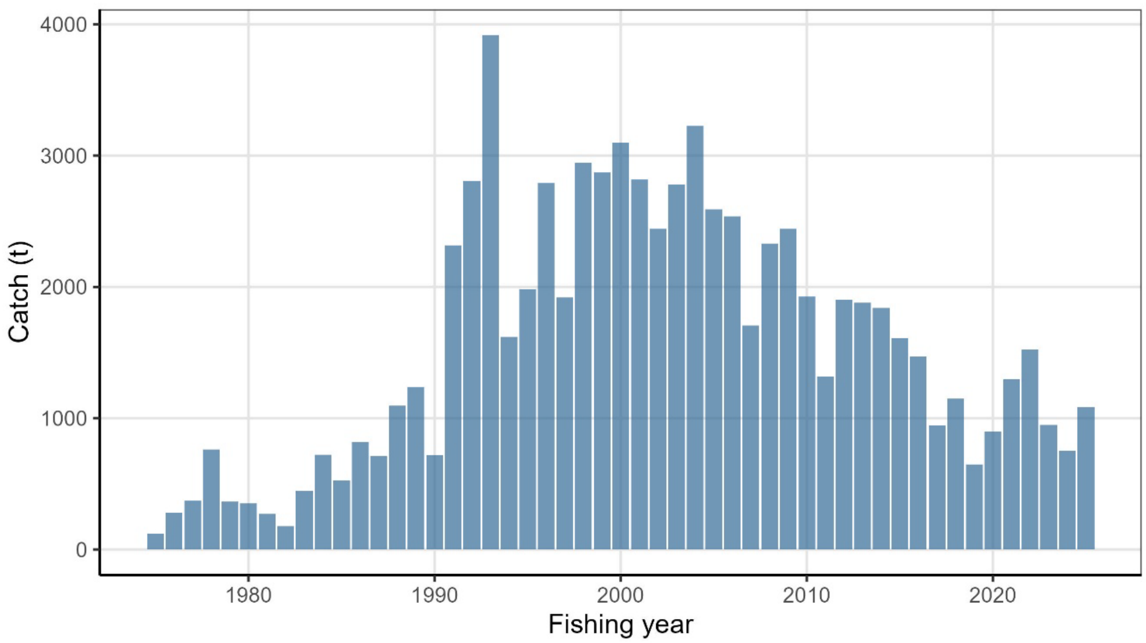

Figure 3: Annual reported catch of Sub-Antarctic hake for the fishing years 1974–75 to 2024-25, with the assumed catch for 2025–26.

2.1.2 Biological parameters

Revised length-weight and growth curve parameters were described by Dunn et al. (2025), using all available age at length data. Revised length-weight parameters and Bayesian von Bertalanffy growth curves are given in Table 2. However, the differences between these and the parameters for the length weight (Horn 2013a) and growth estimates (Horn 2008, 2013a) previously used were relatively small, and had little effect on the stock assessment outputs.

Parameters for natural mortality were given by Horn & Francis (2010), based on estimates derived from age data using methods of Chapman & Robson (1960), Ricker (1975), and Hoenig (1983). The stock recruitment relationship was assumed, based on values used for previous assessments (Dunn et al. 2021b) and ageing error from the values given by Horn & Francis (2010). Males and females were assumed to be 50:50 at recruitment to the model (i.e., at age 1) and all mature fish were assumed to spawn in each year (Table 2).

Maturity values were revised by Dunn et al. (2025) as estimated rates of maturity (i.e., proportions at age that are mature) and not rates of maturation (i.e., the proportion of immature fish at each age that become mature), as previous assessments where maturity was not in the partition had inadvertently assumed that the maturation rates were the same as maturity rates. These updated the previously used estimates by Horn (2008). The revised estimates of the rate of maturity are given in Table 3.

Table 2: Biological parameters for Sub-Antarctic hake.

Relationship	Reference	Parameter (units)	Both	Male	Value Female
Natural mortality*	(Horn & Francis 2010)	M (y^{-1})		0.19	0.19
von Bertalanffy growth	(Dunn et al. 2025)	L_∞ (cm)		89.0	113.9
		k (y^{-1})		0.29	0.17
		t_0 (y)		-0.36	-1.07
		CV		0.07	0.09
Length-weight	(Dunn et al. 2025)	a (g cm^{-1})		2.35e-06	2.46e-06
		b		3.257	3.246
Beverton-Holt stock recruitment relationship					
Stock recruitment steepness	(Horn & Francis 2010)	h	0.8		
Recruitment variability		σ_R	1.1		
Ageing error	(Horn & Francis 2010)	CV	0.08		
Proportion male at birth			0.5		
Proportion of mature that spawn			1.0		
Maximum exploitation rate		U_{max}	0.99		

* Assumed value but also estimated in a sensitivity model.

Table 3: Maturity-at-age for Sub-Antarctic hake (Dunn et al. 2025).

Age (y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Male	0.000	0.001	0.009	0.098	0.410	0.694	0.821	0.885	0.969	0.990	0.999	1.000	1.000	1.000
Female	0.000	0.002	0.009	0.048	0.192	0.481	0.740	0.875	0.936	0.966	0.983	0.992	0.997	1.000

2.1.3 Observations

Observation data for the Sub-Antarctic hake stock assessment included the biomass indices from the series of Sub-Antarctic Summer (Nov-Dec) and Autumn (Apr-May) trawl survey series from RV *Tangaroa*, and age compositions from the surveys and commercial fishery (Table 4).

Survey biomass indices were available from 1992 to 2025 (Table 5), with the Autumn series between 1992 and 1998. As the September series consists of only one survey, this was excluded from the observations in the assessment model. The summer series of surveys was based on core strata from the Sub-Antarctic survey that had been sampled in each year, comprising 300–800 m depth strata and including 800–1000 m depth strata in the Puysegur Bank region but excluding Bounty Plateau. The second series, April–May, comprised 300–800 m depth strata, excluding the 800–1000 m strata in the Puysegur Bank area and excluding the Bounty Plateau.

In addition, the December 2016 survey (2017 model year) was unable to be completed due to bad weather. The biomass estimates were scaled up using factors based on the proportion of hake biomass in those strata in previous surveys from 2000 to 2014, but due to the uncertainty in this estimate, this data point and the associated age compositions were excluded from the assessment model.

The trawl survey series biomass indices and associated coefficients of variation (CVs) are shown in Figure 4 and given in Table 5 (see also appendix A in Dunn et al. 2023b). While survey biomass indices suggested a sharp decline after 1992, the series has indicated a flat trend up until 2015, and a slow decline thereafter. Lognormal errors, with known CVs, were assumed for all relative biomass observations from the surveys. The CVs available for those observations of relative abundance 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. The additional variance, termed process error, was estimated in the models at maximum posterior density (MPD) level only because mixing of these process error parameters is generally poor when using the Metropolis-Hastings MCMC algorithm. Initial and the adjusted sample sizes that include process error for all observations are shown in Figure 5.

Age compositions for the trawl survey series (Dunn et al. 2025) were available for each of the surveys (Figure 7) and were included as sexed observations with multinomial likelihoods. The commercial age compositions were assumed to be observations of the removals, split into summer (September–March) and winter (April–August) fisheries (Figure 6) and were included in the model as sexed observations with multinomial likelihoods (Figure 7). As age observations from otolith readings for the years 1991–1993 were considered to be uncertain and the associated length compositions did not appear well sampled, age composition data for 1991–1993 were excluded from the base case assessment (see Figure 5). Ages 2–25+ (where 25+ was a plus group of all fish aged 25 and older) were used in the model for all age composition data. The plus group at 25 was used as fish older than this were sparse and likely to be poorly represented in the scaled age compositions.

The multinomial sample sizes (N) for the age composition observations were generated using a two-step process. First, the sample sizes were derived by assuming 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 robust non-linear least squares fit of $\log(c_i) \sim \log(P_i)$ (labelled the initial sample size). Second, estimates of the effective sample size, N_j', were made from iterative model fitting following method TA1.8 as described in Appendix A of Francis (2011). Initial and effective sample sizes for commercial catch-at-age data are given in Figure 5.

Ageing error was accounted for by modifying the likelihoods for the age composition data such that *E*i was replaced by *E*'i, where *E*'i were the expected age compositions multiplied by an ageing error misclassification matrix *A*. The error misclassification matrix was derived from a normal distribution with constant CV = 0.08 (Horn & Francis 2010).

Table 4: Observations used in the Sub-Antarctic hake stock assessment. Further summary details are given in Appendix A of Dunn et al. (2025).

Data series	Model years
Survey biomass (*Tangaroa*, Nov-Dec)	1992–94, 2001–10, 2012–13, 2015, 2019, 2021, 2023, 2025
Survey age compositions (*Tangaroa*, Nov-Dec)	1992–94, 2001–10, 2012–13, 2019, 2021, 2023, 2025
Survey biomass (*Tangaroa*, Apr–May)	1992–93, 1996, 1998
Survey age compositions (*Tangaroa*, Apr–May)	1992–93, 1996, 1998
Commercial fishery age compositions	1999–2024

Table 5: Research survey estimates of biomass (and associated CVs) for the Sub-Antarctic survey. Note the September series was not used in the base case mode for the stock assessment.

Model		Nov-Dec series [1]		Apr–May series [2]		Sept series [2]	
year	Vessel	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
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*	1 855	0.23				
2013	*Tangaroa*	2 428	0.23				
2015	*Tangaroa*	1 477	0.25				
2017[3]	*Tangaroa*	1 373	0.34				
2019	*Tangaroa*	1 675	0.25				
2021	*Tangaroa*	1 572	0.20				
2023	*Tangaroa*	1 285	0.18				
2025	*Tangaroa*	1 521	0.16				

[1] Series based on indices from 300–800 m core strata, including the 800–1000 m strata in the Puysegur Bank area, but excluding Bounty Plateau.
[2] Series based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in the Puysegur Bank area and the Bounty Plateau.
[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. Due to the uncertainty in this estimate, it was excluded from the assessment.

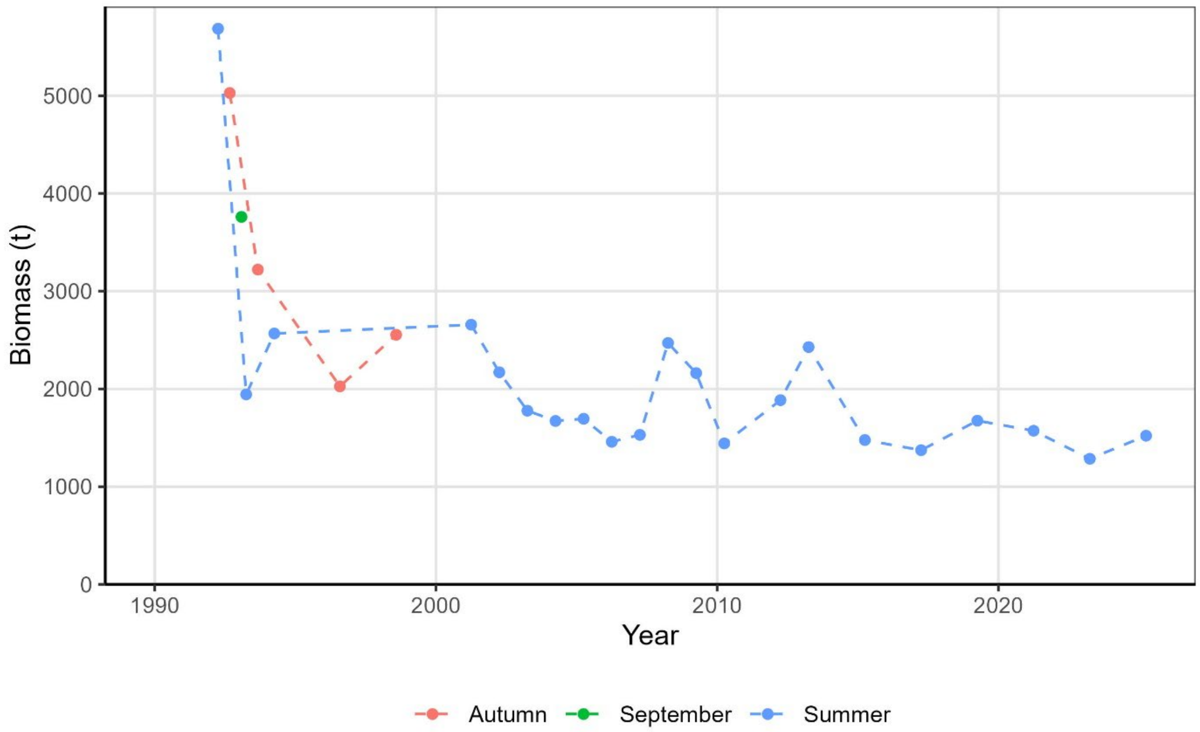

Figure 4: Biomass indices for the Apr-May, Sep, and Nov-Dec trawl survey series on the Sub-Antarctic, 1992–2025.

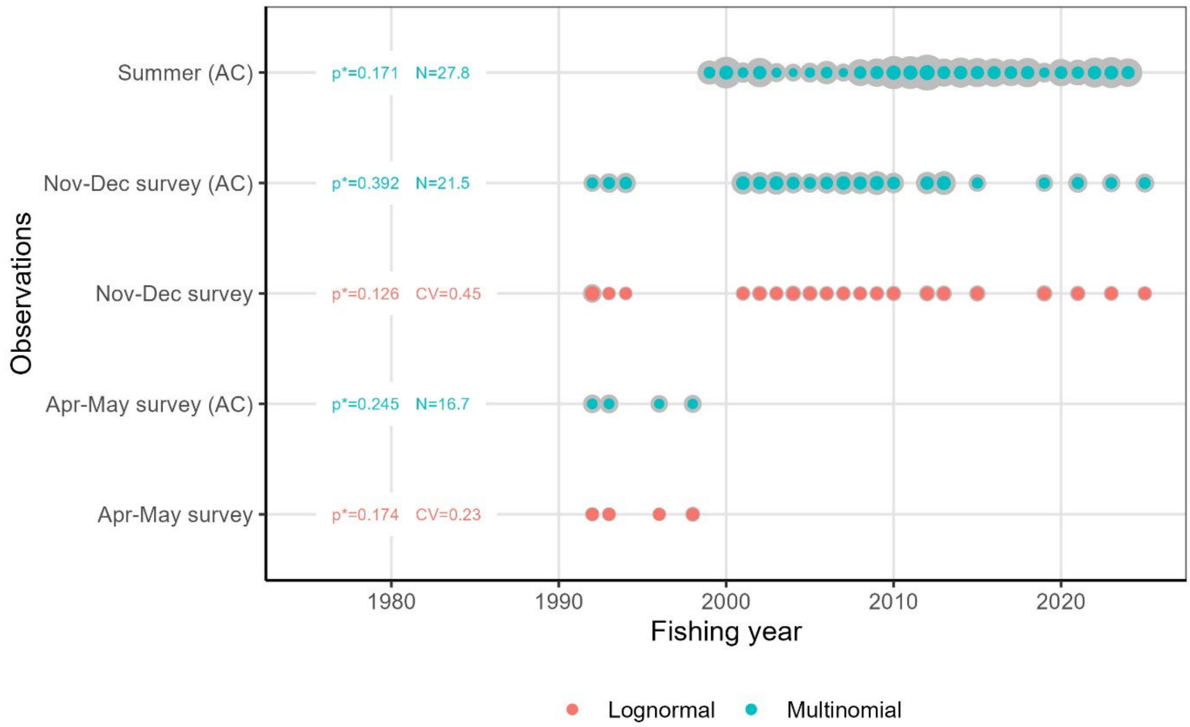

Figure 5: Model observations for the base case model. The coloured points represent the relative effective sample sizes (mean-adjusted for comparability between observation types) for each year and observation type (rows: age-compositions (AC), Nov-Dec and Apr-May survey series) and likelihood (colour), with the grey outline indicating the initial sample size before reweighting. p* was the multiplier used to adjust the multinomial Ns in each observation from the Francis reweighting (multinomial likelihoods) or the process error CV (lognormal likelihoods).

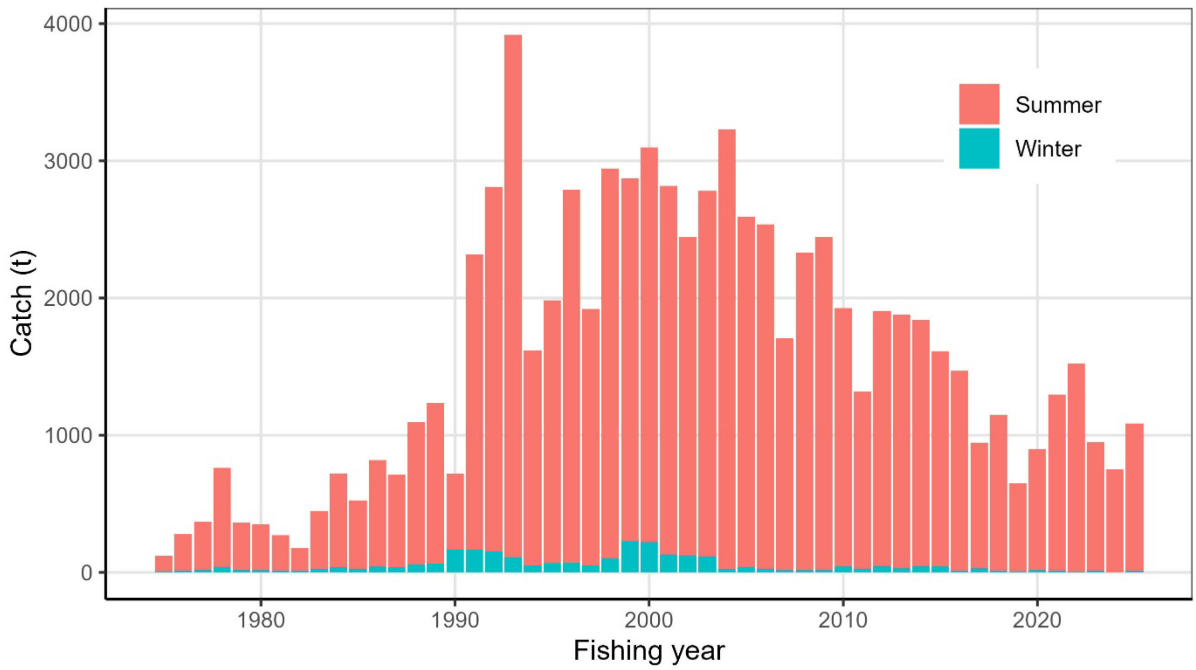

Figure 6: Catch history (t) for hake for the summer and winter fisheries in the Sub-Antarctic, 1974–2025 fishing years and the assumed catch for 2026 .

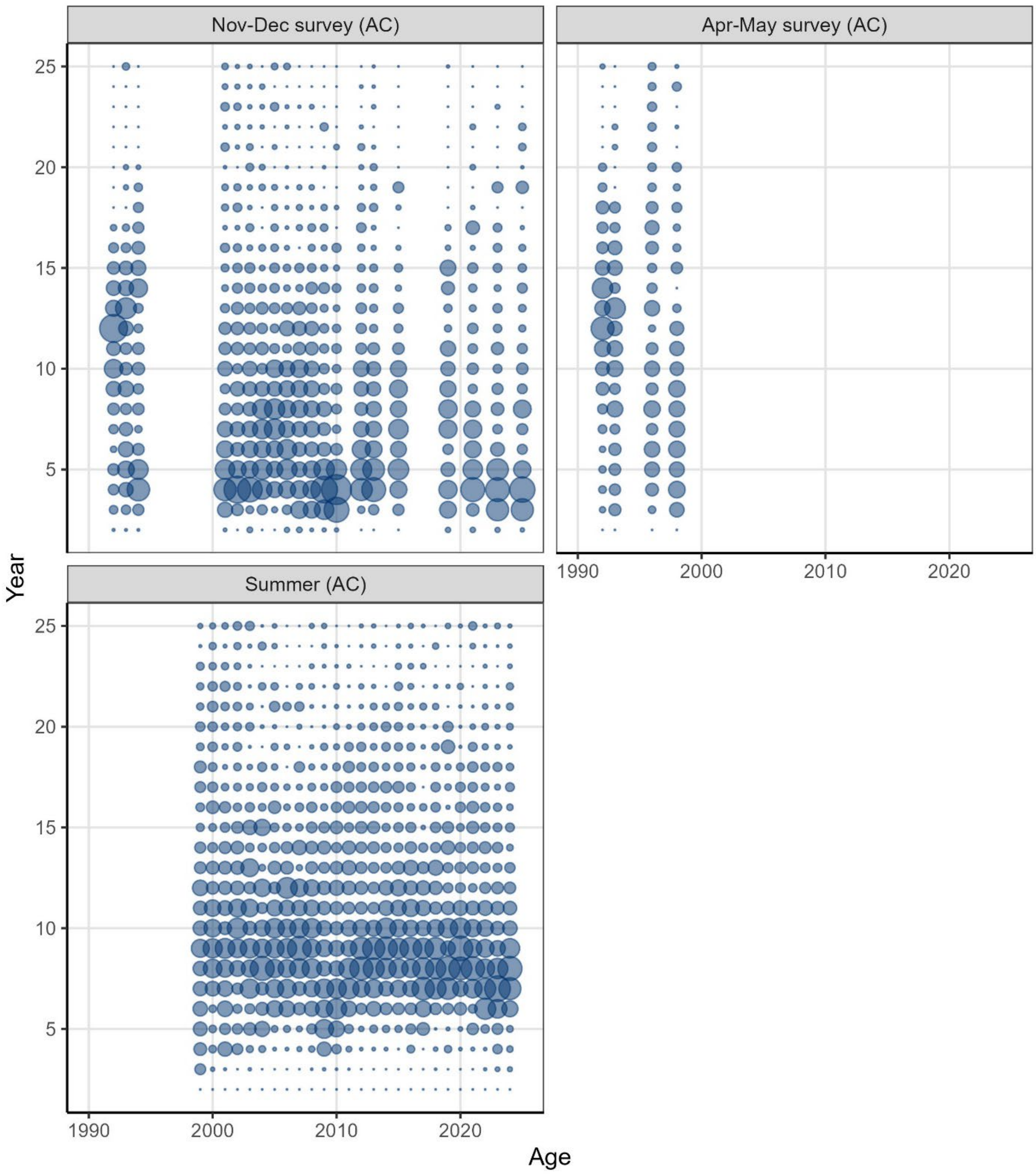

Figure 7: Relative age compositions for the (top left) Nov-Dec *Tangaroa* trawl survey series, (top right) Apr-May *Tangaroa* trawl survey series, and (bottom left) commercial age compositions for the summer fishery for years 1990–2024 for ages 2-25+, where 25+ represents a plus group of fish aged 25 and older.

2.2. Model structure

Stock assessments have been carried out for hake since 1991–92 (Colman et al. 1991) and have used an integrated assessment model implemented in CASAL since 2000–01 (Dunn 2001). This year, the assessments were carried out using Casal2 (Casal2 Development Team 2024a) with analyses using the *R* package *R4Casal2* (Marsh & Dunn 2024).

The primary source of abundance information is the Sub-Antarctic trawl survey, using the strata that formed a consistent time series since 1992 (see Table 5 above). The model was a sex- (male and female) and age-structured model with ages from 1 to 30, whereby the number of male and female fish of each age from 1 to 30 was tracked through time, and the last age group was a plus group (i.e., an aggregate of all fish aged 30 and older). The population was initialised assuming an unfished equilibrium age structure at an initial biomass (i.e., with constant recruitment). The initial biomass was estimated by the model. The model was run from the 1975 to 2025 years, and the annual cycle was broken into three discrete time steps: summer (September–March, time step one), winter (April–August, time step two), and then an age incrementation step (time step three). The annual cycle assumed in the model is described in Table 6.

In the first time step, the age of all fish was incremented by one year, with fish in the plus group remaining in that group. Biomass calculations at any point in the model were made by multiplying the number of fish in each year class by the size-at-age relationship and the assumed length-weight relationship for each sex separately.

Recruitment was assumed to occur at the beginning of the first time step, to be 50:50 male to female, and to be the mean (unfished) recruitment (R_0) multiplied by the spawning stock-recruitment relationship. Recruitment was assumed constant and equal to R_0 times the stock recruitment relationship for years where adequate age frequency data were not available (see later). Future recruitment was assumed to be distributed with a mean and the variability observed in the estimated historical recruitment for each Markov chain Monte Carlo (MCMC) iteration, either from resampling or simulated from time-series models of estimated historical recruitment (see below for more detail).

The catch history for the fishery was assumed as mostly occurring in the first time step (summer) based on the relative reported catches in each month; about 78% of the catch occurred from September to March. For the years before 1991, when catch by month information was not available, the catch was assumed to be in summer. Fishing mortality for each fishery (i.e., summer or winter) was applied by removing half of the natural mortality for the time step, then mortality from the fishery, then the remaining half of the natural mortality for the time step.

The fishing selectivity parameters were estimated by the model through fitting of the observations, particularly the fisheries age frequency data. The maturation process was applied at the beginning of the winter time step. Maturity was specified as the time-invariant proportion of male and female fish-at-age that were mature and calculated as at the middle of the winter time step.

Model parameters were estimated by minimising the total objective function, which was the sum of the negative log-likelihoods from the data, the negative-log priors, and the penalty functions used to apply model constraints. Penalties were applied to catch data if the biomass from the model was too small to allow the catch to be taken, but this did not occur in any of the scenarios modelled. Initial fits were evaluated at the mode of the posterior distribution (MPD). MPD model fits were evaluated by investigating jitter start values to confirm that MPD had been achieved, evaluating MPD fits and residual patterns, and by qualitative assessment of the MPD profile distributions (i.e., by evaluating the minimum objective function while fixing one parameter and allowing all other parameters to vary). Residual patterns in the age compositions were investigated using one-step-ahead (OSA) residuals (Trijoulet et al. 2019) as, unlike Pearson residuals, these are more appropriate for non-normal multivariate distributions that have inherent correlations (Trijoulet et al. 2023).

The initial spawning stock biomass (B_0) was estimated by the model, as were year class strengths and selectivity ogives. The two *Tangaroa* survey selectivity ogives were fitted as double normal curves with an asymptotic right-hand limb (i.e., approximating a logistic curve). The fishery catch and age composition data were included using an 'areas-as-fleets' approach, using the summer and winter fisheries. In some model sensitivity runs, area-based strata were used from 2- to 4-strata depending on the run. Fishery selectivity ogives were fitted as logistic curves because double normal assumptions typically estimated a curve that was very close to a logistic shape. Selectivities were assumed to be constant for all years in each fishery or survey. The estimated parameters, their shape, prior assumptions, and bounds are summarised in Table 7.

A Student-t distribution with 4 degrees of freedom and relatively high standard deviations was used for each non-informative parameter. The exception was the choice of informed priors for survey catchability coefficient when used in a sensitivity model. Hence, unlike previous assessments for the Sub-Antarctic, the prior for the *Tangaroa* survey *q's* in the base case was assumed to be non-informative and was a Student-t distribution with mean equal to the prior calculated by Kienzle et al. (2019) but with a large variance parameter.

Bayesian inference was used to obtain samples from the posterior distribution of model parameters using the Metropolis-Hastings algorithm (Gelman et al. 1995, Gilks et al. 1998). MCMCs were initialised using a random starting point near the MPD (generated from a multivariate Student's-t distribution, centred on the MPD with covariance equal to the inverse Hessian matrix), with the correlation matrix derived from the inverse Hessian. MCMCs had a burn-in length of 1×10^6 iterations, with every 2000th sample taken from the next 2×10^6 iterations (i.e., a final sample of length 1000 was taken after the burn-in to sample from the posterior distribution). Chains were investigated for evidence of non-convergence with qualitative investigation of MCMC traces and multiple-chain comparisons (i.e., three chains of 1000 samples each), and $\hat{r}$ statistics and the effective sample size estimates (Gelman et al. 2015, Vehtari et al. 2017). Based on the recommendations of Monnahan (2024), $\hat{r}$ values less than 1.05 are considered evidence of acceptable convergence and effective sample sizes above 400 are considered adequate.

Table 6: Annual cycle of the Sub-Antarctic hake stock assessment model, giving the time steps, and the monthly timing of biological processes (ageing, recruitment, maturation, growth, natural mortality, and spawning) marked by X, and observations (resource surveys and associated age frequencies, and observer age frequencies (AFs), and CPUE indices (where used).

	Monthly timing of biological and fisheries processes						Model timing of biological and fisheries processes				
	Recruitment	Maturation	Trawl catch (%)	*Tangaroa* resource surveys (Biomass and AFs)	Fishery AFs	Fishery CPUE	Model timestep	Ageing (before maturation)	Proportion of growth	Proportion of natural mortality	Trawl catch (%)
							Year start				
Sep	X		17	1 (Sept 1992)			1		0.20	0.58	78
Oct			22								
Nov			18		X	X					
Dec		X	9	19 (Dec 1990 to 2020)							
Jan			6								
Feb			3								
Mar			3								
Apr			3	4 (Apr 1992 to 1998)			2	X	0.50	0.42	22
May			4								
Jun			1								
Jul			2								
Aug			11								
							Year end		0.67		

Table 7: The assumed priors for key parameters (when estimated) for the Sub-Antarctic hake stock assessment. The parameters (and the transformation used) are mean (mu), and either σ (scale parameter for the Student's-t and standard deviation for the normal) or CV (for the lognormal).

Parameter (transformation)	Distribution	Parameters		Bounds	
		Mu	Sigma/CV	Upper	Lower
B_0 (log)	Student-t (μ, σ)	11.3	5	10	13
Year class strengths (simplex)	Lognormal (μ, CV)	1.0	1.1	-10	-10
Trawl survey 's	Student-t (μ, sigma)	0.16	10	0.01	0.40
Selectivities	Student-t (μ, σ)	8	30	1	25–200[1]
M	Normal (μ, σ)	0.19	0.05	0.05	0.40

[1] A range of maximum values was used for the upper bound depending on the specific selectivity parameter.

2.3. Model sensitivity analyses

Sensitivity analyses were carried out where the assumptions or choices of model observations might impact the outputs and conclusions (Table 8). These included evaluation of assumptions of lower or higher natural mortality; applying an informed prior on the survey catchability coefficients (*q*); including the Nov-Dec 2016 survey biomass estimate; including fishery age compositions for 1991–1993; splitting the fishery into two areas, using a 'fleets-as-areas' model based on the *k*=2 strata identified in Dunn et al. (2025); setting the additional process error CV for the surveys at zero; up-weighting and down-weighting the fishery and survey age compositions data relative to the biomass observations; lower values of steepness; replacing the survey observations (both the Nov-Dec and Apr-May series) with a CPUE index for the fishery; and adding additional catch to account for potential underreporting in the early years of the QMS (base+).

Natural mortality was investigated using fixed values and sensitivity runs from the base case. First, constant natural mortality over ages (*M*-at-age) of 0.19 y^{-1} using lower and higher values of 0.15 y^{-1} (low-*M*) and 0.23 y^{-1} (high-*M*) were investigated.

The value of steepness (*h*) for the Beverton-Holt stock recruitment relationship was based on an assumption in Horn & Francis (2010) with *h*=0.84. Since then, *h* has not been re-evaluated in New Zealand hake assessments. Thorson (2019) developed a model that provides predictions of productivity for families, species merging phylogenetic comparative methods and structural equation models. This was updated by Thorson et al. (2023) for steepness and available as an *R* package *FishLife* (Thorson et al. 2023) using data from the RAM legacy database (Ricard et al. 2012) and FishBase (Froese & Pauly 2000). Using these data and the method in Thorson et al. (2023) to derive a prediction of steepness for hake *(Merluccius australis*), *h*=0.50 (CV=0.16) was estimated and used as the value for *h* in a sensitivity model. In addition, a sensitivity run using *h*=0.66, a point halfway between the estimate of using the method of Thorson et al. (2023) and that assumed by Horn & Francis (2010) was done. Two additional models were conducted where estimation of *h* was attempted with one of two priors: a normal with mean 0.84 and standard deviation 1.0 (based on Horn & Francis 2010), and a normal with mean 0.50 and standard deviation 0.16 (derived using the method of Thorson et al. 2023), both with bounds 0.2–1.0. However, in both cases, estimation was not well defined with *h* estimated at the upper bound, and these were not progressed further.

Although initial investigation suggested that the selectivity shapes for the fishery were flat topped, double normal selectivities were employed that that allowed the right-hand limb to be estimated as a decline.

In addition to the model sensitivities, model retrospectives were also carried out. These sequentially removed each year's catch and observations and reduced the year classes that were estimated to exclude the most recent year.

Table 8: Summary of the base case (grey) and sensitivity stock assessment model runs.

Run	Model
R1.1	2022 base case (updated in Casal2)
R5.0	2025 base case
R5.1	2025 base case with high *M*
R5.2	2025 base case with low *M*
R5.3	2025 base case with informed prior on the survey catchability
R5.4	2025 base case including 1991–1993 fishery age compositions
R5.5	2025 base case including Nov-Dec 2016 survey biomass
R5.6	2025 base with 2 fleets as-areas
R5.8	2025 base case with no survey process error CV
R6.1	2025 base case with up-weighted age data
R6.2	2025 base case with down-weighted age data
R7.1	2025 base case with $h = 0.66$
R7.2	2025 base case with $h = 0.5$
R7.7	2025 base case with CPUE
R8.0	2025 base+

2.4. Projections

Models were projected from the current year assuming (i) a constant catch equal to the mean of catches reported for the most recent three years with data (2023–24 to 2024–25, 1084 t) or (ii) using the current TACC (3701 t). Catch splits were assumed based on the ratio of catches for the fisheries in the model averaged over the most recent three years.

Two scenarios were considered in projections for recruitment: (i) an assumption that future recruitment was similar to the entire time series of historically estimated recruitments (1974–2019) or, (ii) an assumption that future recruitment was similar to the recruitment estimates from the most recent ten years (2010–2019). In both cases, future recruitments have been assumed to be independent samples from estimated historical recruitments. Retrospective analyses (e.g., where each year of observations was sequentially removed from the model, and the range of year classes estimated was modified to remove the most recent year in each iteration) suggested that recent recruitment in the retrospectives was estimated higher than that which is estimated once additional years data is added. Hence, the projections that assume the most recent 10 years as an average for future year classes may be a more appropriate choice.

3. RESULTS

3.1. CASAL and Casal2 comparison

The 2021 assessment base case and sensitivities for Sub-Antarctic hake were implemented using CASAL (Bull et al. 2012). The 2024 models were implemented in Casal2 (Casal2 Development Team 2024a), and a comparison between the CASAL and the Casal2 implementation was made using the same model structure, parameters, and observations as for the 2021 base case. No parameter transformations were applied, and penalties were used to constrain YCS to have mean one in Casal2 in the same manner as in CASAL.

Model estimates of B_0 and biomass in 2021 (B_{2021}) from the CASAL and Casal2 implementations were similar (Table 9) with the same SSB trajectory (Figure 8) and values for the components of the objective function, and there was no difference in MPD estimates of YCS between CASAL and Casal2 (Figure 9). The estimated survey catchability from the two models was also the same. At MCMC, the models were also similar, with very similar SSB trajectories (Figure 10).

Table 9: MPD and MCMC estimates of B_0 and B_{2021} (with 95% CI for MCMC estimates) for the 2021 base case implemented in CASAL and Casal2.

Model	MPD		MCMC	
	B_0	B_{2021}	B_0	B_{2021} (%B_0)
CASAL	61 239	36 501	61 253 (43 871–108 765)	39 161 (23 259–78 335)
Casal2	61 381	36 592	61 230 (43 657–102 070)	38 840 (23 067–72 928)

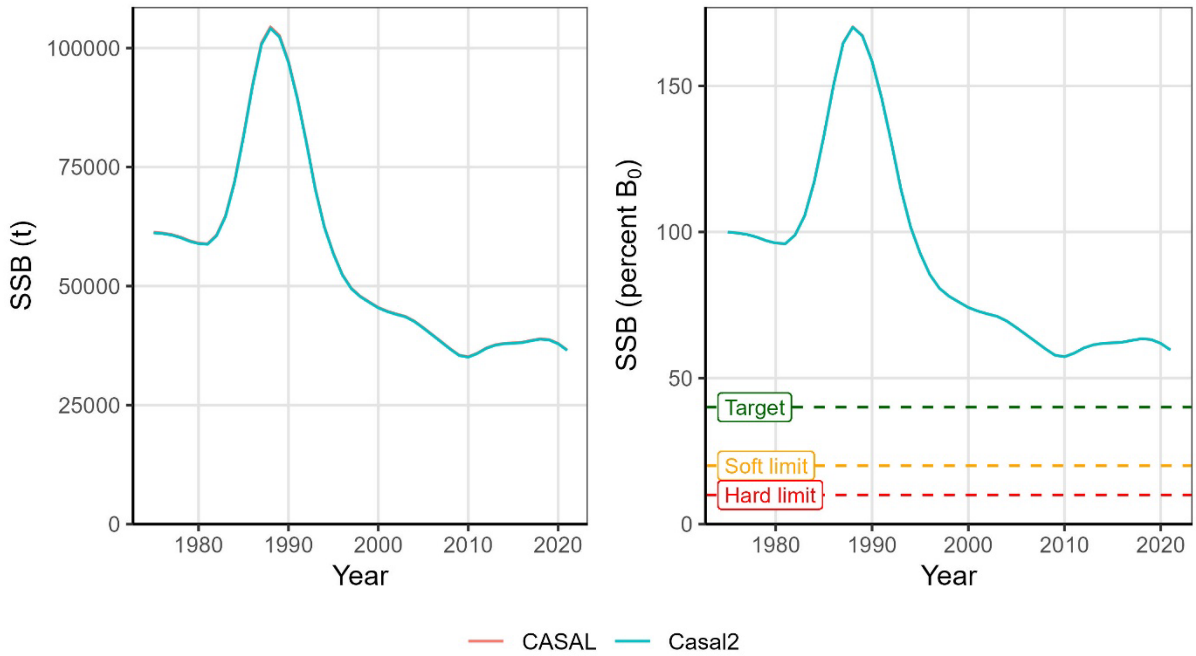

Figure 8: 2022 MPD base case CASAL model and the equivalent Casal2 model for (left) SSB by year and (right) SSB as a percentage of B0 for 1975–2021.

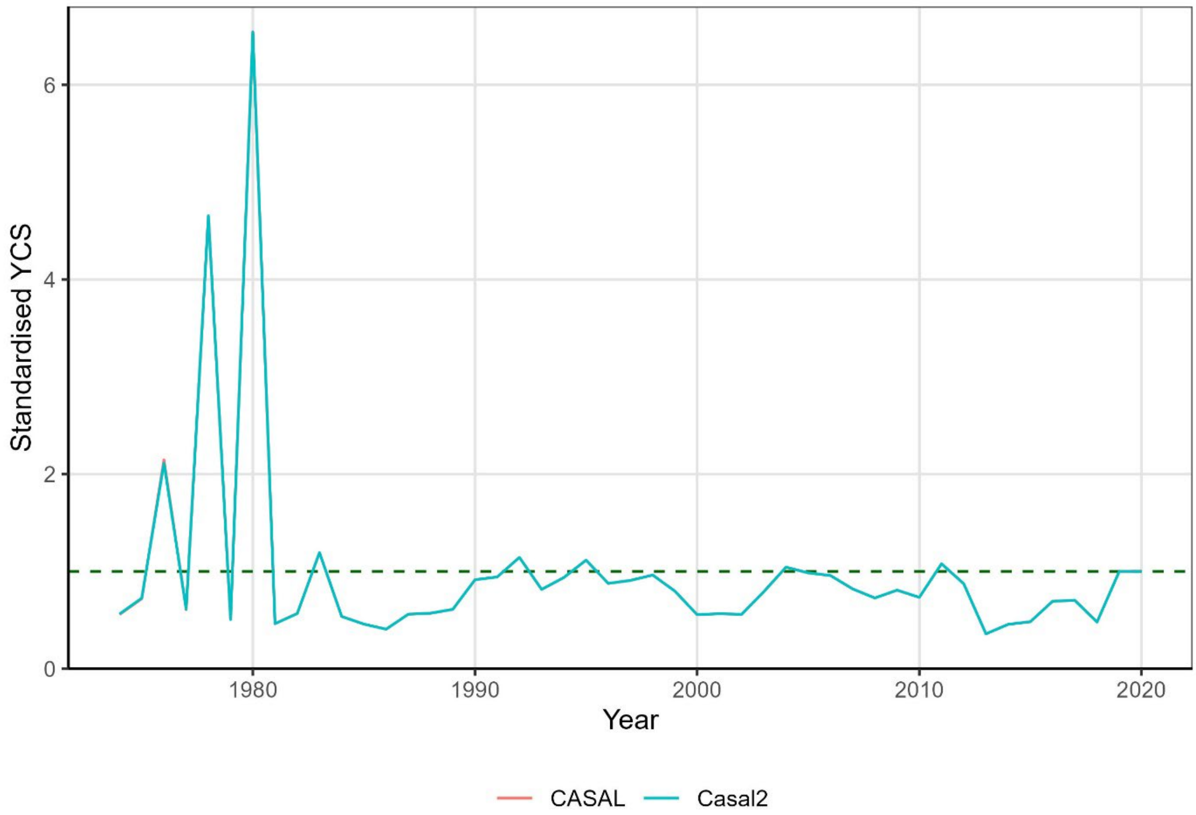

Figure 9: 2022 MPD base case CASAL model and the equivalent Casal2 model for estimates of year class strengths (1974–2018) for the years 1974–2020.

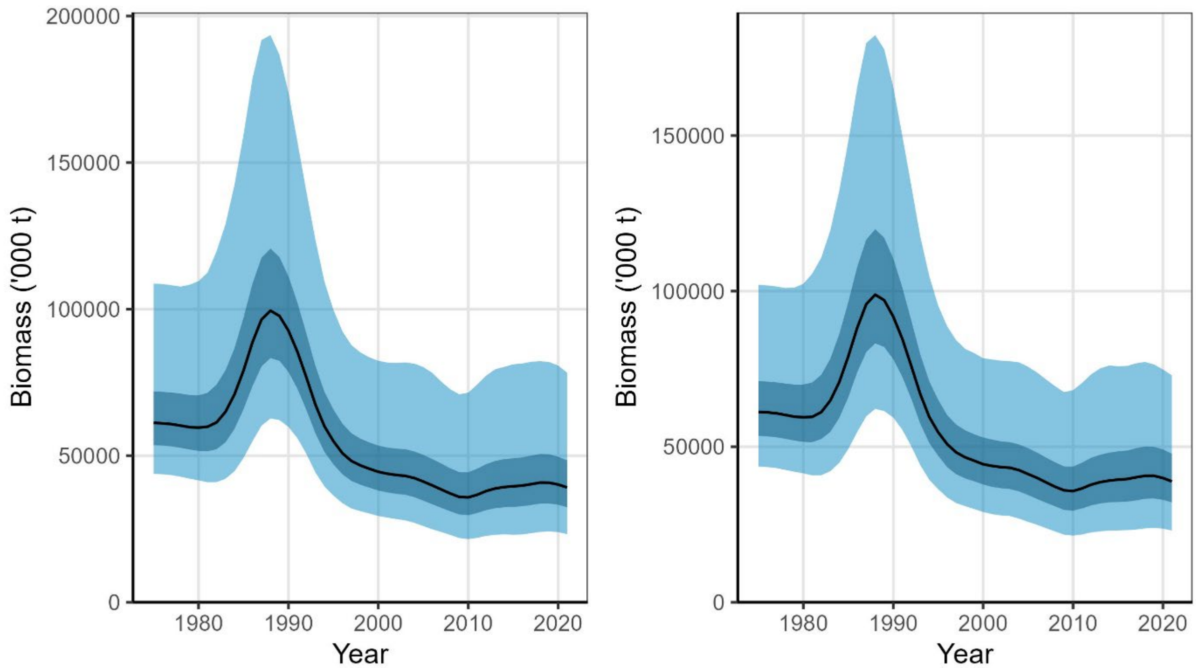

Figure 10: 2021 base case CASAL model (left) and the equivalent Casal2 model (right) for MCMC estimates of SSB by year for 1975–2021 (with the interquartile range shown in dark blue and the 95% CIs in light blue).

3.2. Base model MPD results

A base case model that updated the 2021 model (Dunn et al. 2021b) was developed, including migrating the 2021 base case to Casal2 (Casal2 Development Team 2024b). The model update included updated trawl survey biomass estimates and age compositions for the survey observations that occurred after the last assessment, as well as new commercial catch data for the 2022–2024 fishing years. The model was also updated with sexed age-compositions and revised priors and methods (see earlier) using Casal2.

The resulting estimated MPD stock trajectories for the base case model are given in Figure 11. Model fits to the survey biomass indices (Figure 12) and age compositions (Figure 13 and Figure 14) were adequate and did not suggest any strong evidence of departure from model assumptions (Figure 15), as were the fits to the commercial age compositions for the fishery (Figure 16).

Selectivity parameters (Figure 17) were reasonable, with some evidence of a decline in the right-hand limb for females in the Nov-Dec *Tangaroa* trawl survey series, but otherwise logistic shaped for the remaining selectivities. The shape of the selectivities for the commercial fishery approximated the maturity ogive and reflected that much of the catch is on mature aged fish. However, all the selectivities showed a considerable male/female difference, with the surveys catching a greater proportion of females, and the fishery a greater proportion of males.

The relative year class strengths are plotted in Figure 18. This indicated a period of slightly stronger year classes in about 1980. Since then, year classes have been below average with little variation. Data from the trawl surveys and the commercial age compositions data were consistent with the estimated year classes, with the observations of stronger year classes from those years showing in both the observed trawl survey and commercial catch-at-age proportions immediately after the fish recruit from the 1980 year class.

Little information was available in the model to estimate the stock recruitment relationship, as the population trajectory had not previously declined to a point where the stock recruitment relationship would impact observed year classes and hence be estimable. Hence the assessment model assumed the steepness (h=0.84), but sensitivities of h=0.5 and h=0.66 were also investigated. The stock recruitment relationship and estimated recruitments are given in Figure 19.

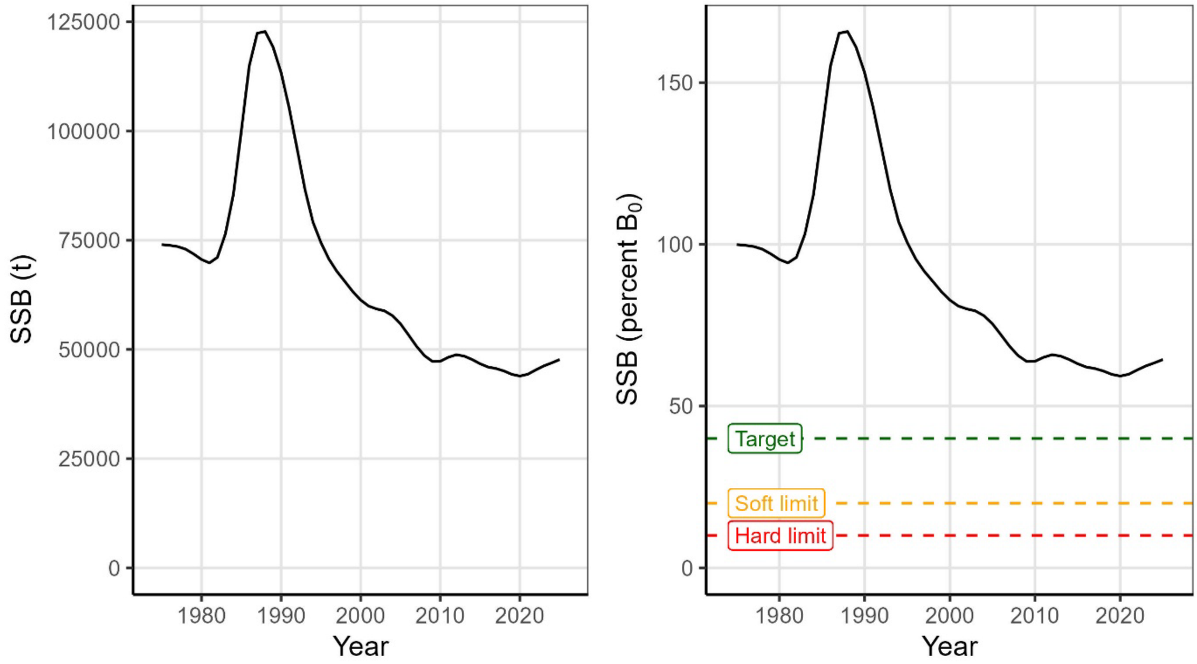

Figure 11: Base case model MPD trajectories for (left) *SSB* biomass and (right) stock status (*SSB*) as a percent of B_0.

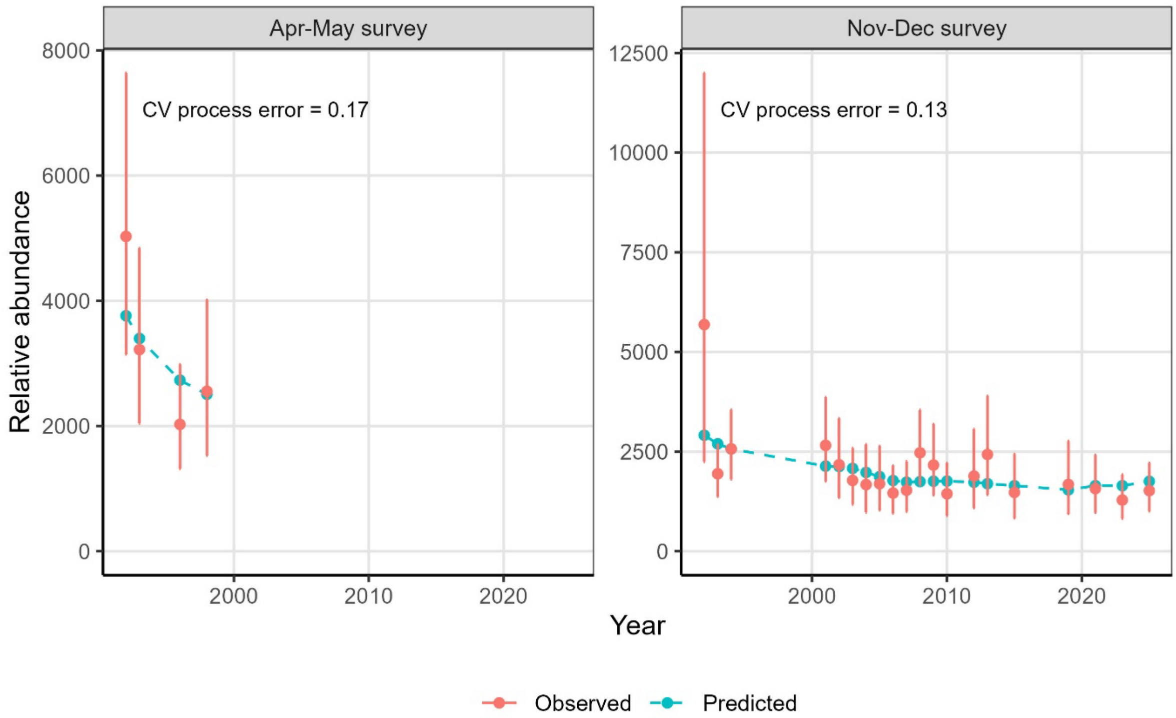

Figure 12: Base case MPD model fits to the Nov-Dec and Apr-May *Tangaroa* survey time series showing the observed biomass (red circles and 95% confidence intervals indicated by the red lines) and expected values by blue points.

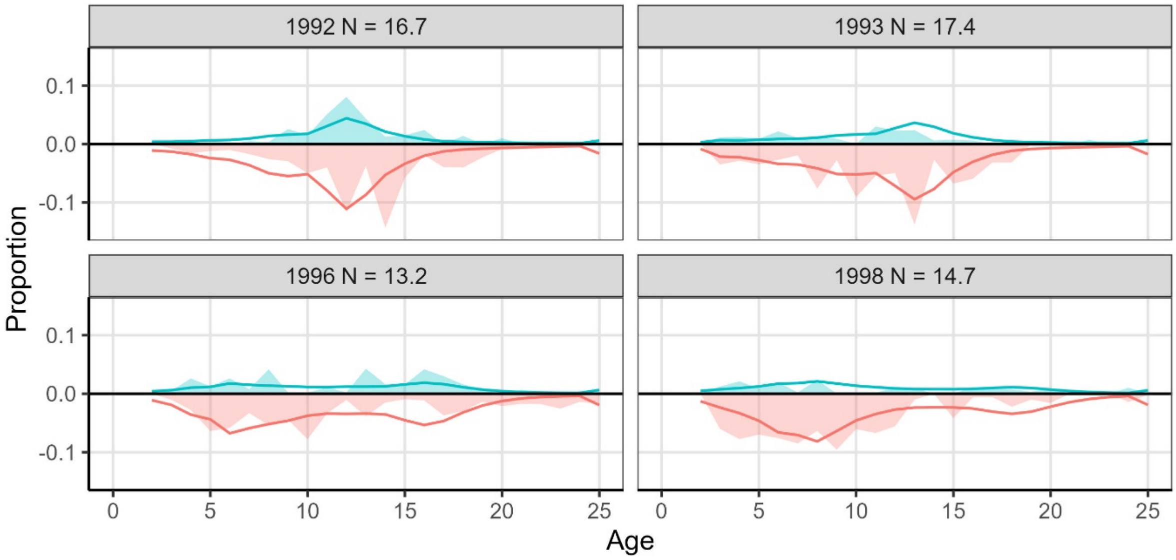

Figure 13: Base case model observed (shaded red and negative axis=female and blue and positive axis=male polygons) and MPD expected (red points and lines) age compositions from the Apr-May *Tangaroa* survey time series for 1992–1996. Age 25 represents a plus group of fish aged 25+.

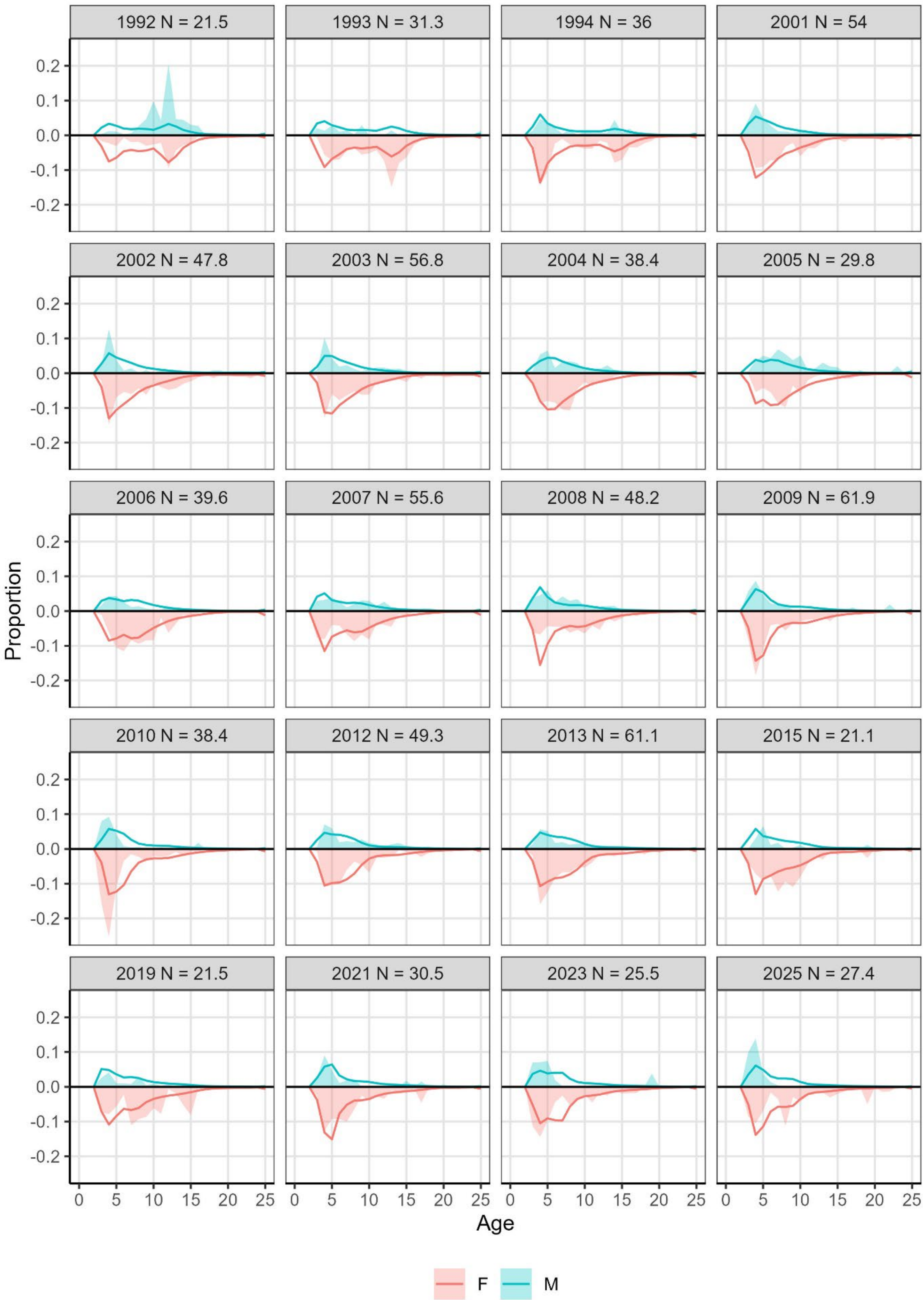

Figure 14: Base case model observed (shaded red and negative axis=female and blue and positive axis=male polygons) and MPD expected (red points and lines) age compositions from the Nov-Dec *Tangaroa* survey time series for 1992–2025. Age 25 represents a plus group of fish aged 25+.

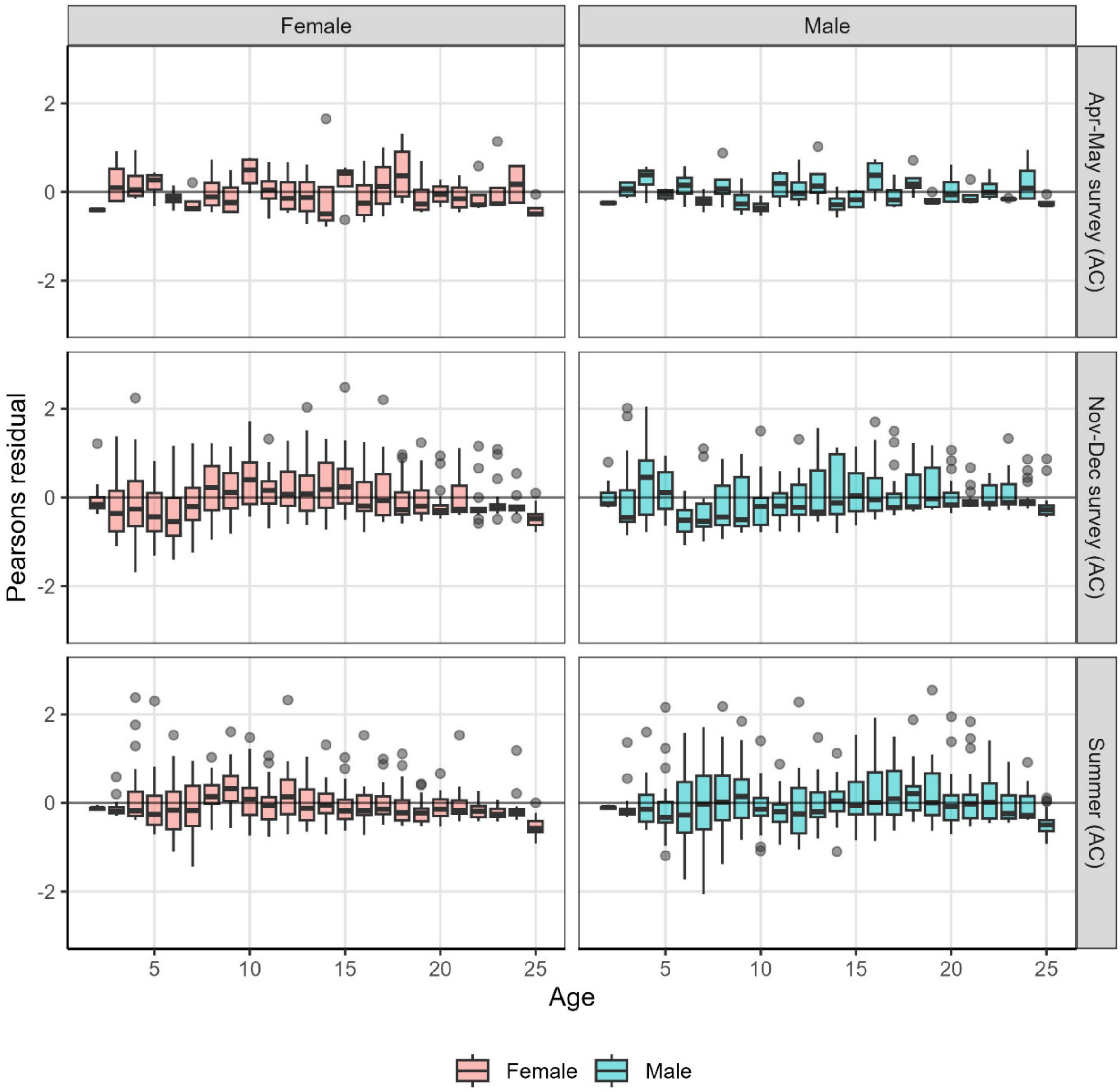

Figure 15: Pearson residuals for the base case MPD model fits to the age compositions data from the Nov-Dec *Tangaroa* survey time series (top), Apr-May *Tangaroa* survey time series (middle) and fishery (bottom) by sex (female=left and male=right). Solid black lines indicate the median, blue boxes the interquartile range, vertical lines are 1.5 times the interquartile range, and black circles are observations outside 1.5 times interquartile range.

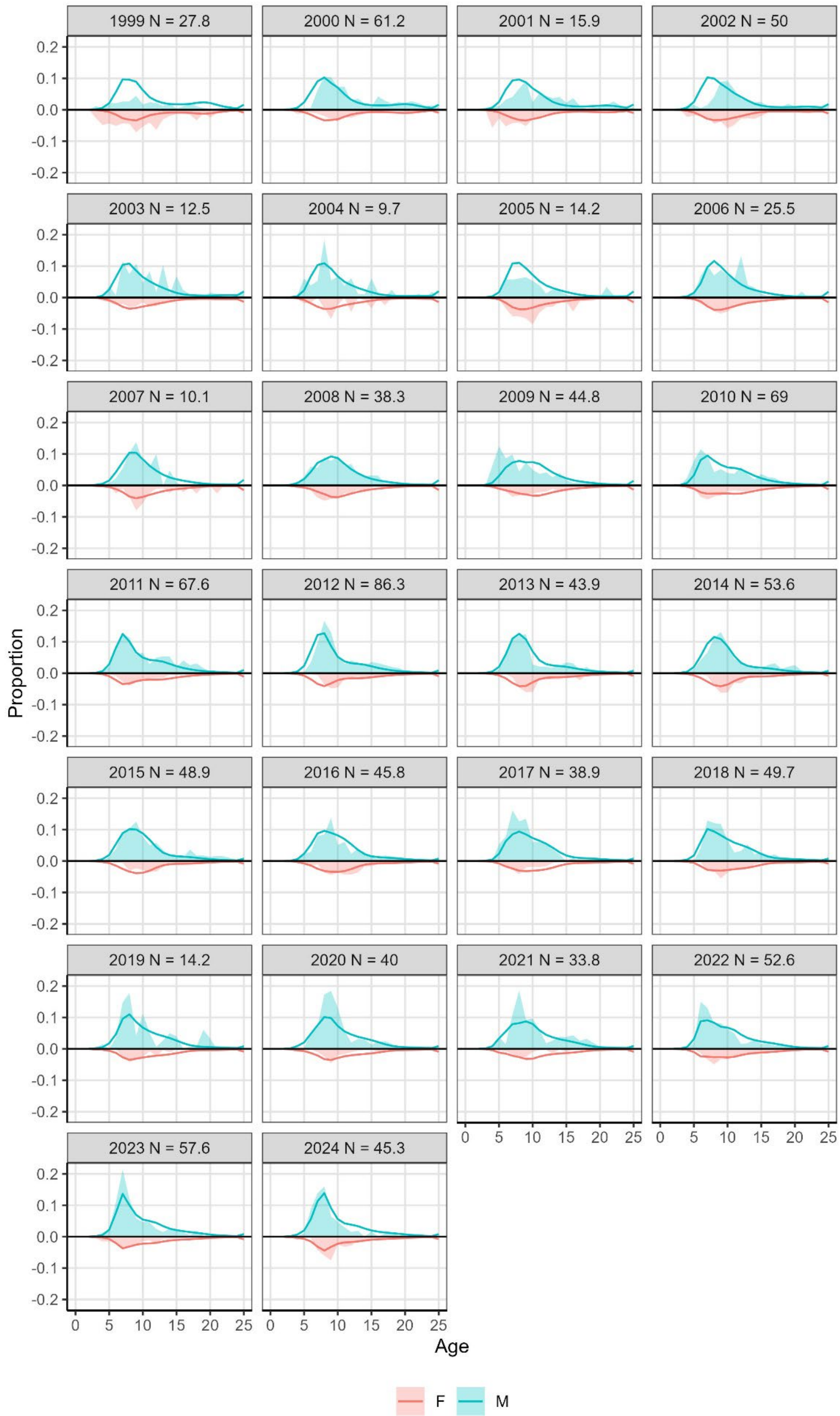

Figure 16: Base case model observed (shaded red and negative axis=female and blue and positive axis=male polygons) and MPD expected (red points and lines) age compositions from the summer fishery for 1999–2024. Age 25 represents a plus group of fish aged 25+.

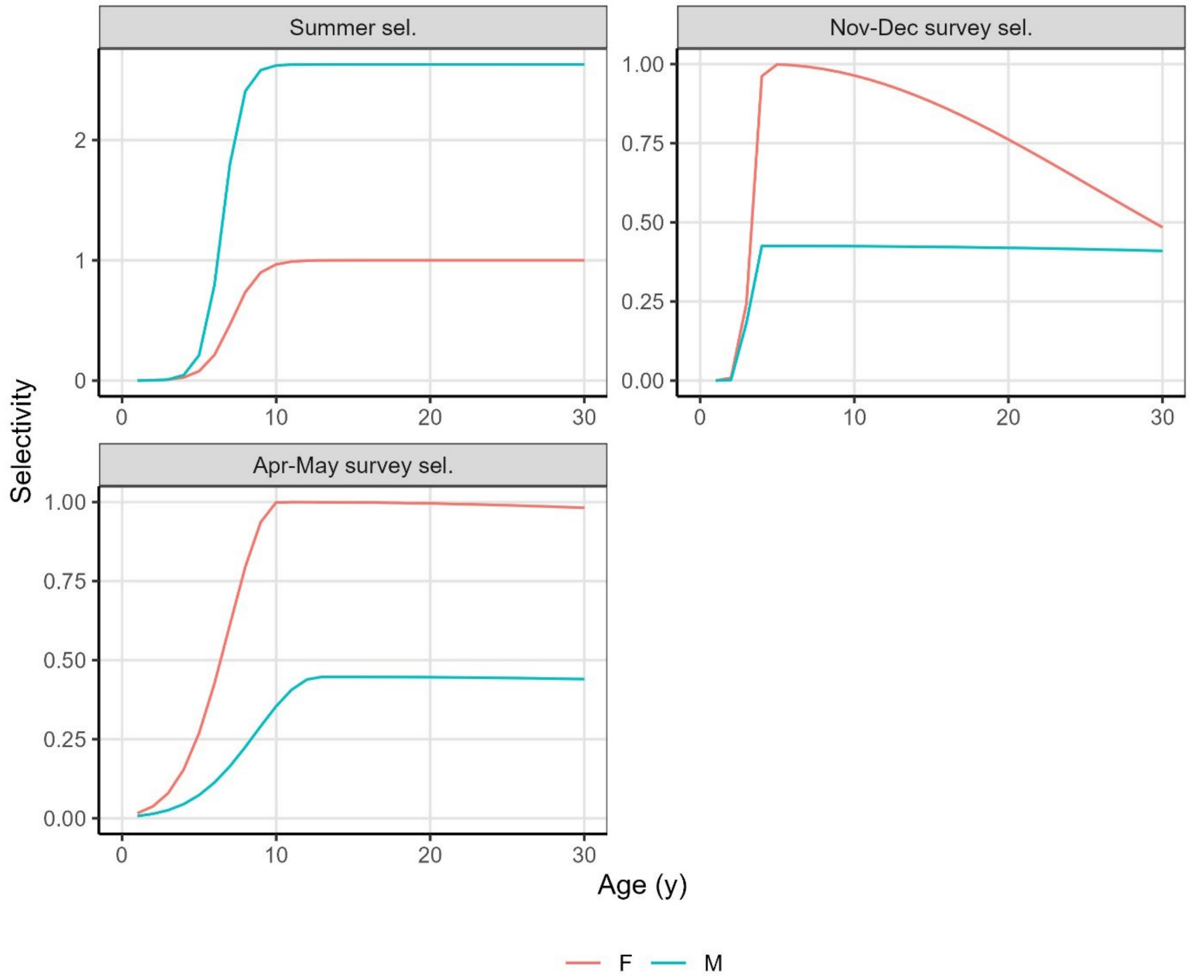

Figure 17: Base case model MPD estimates of the selectivity parameters for the commercial catch selectivities for male (blue) and female (red) hake (summer = summer fishery), and the *Tangaroa* survey selectivity for the Nov-Dec and the Apr-May time series.

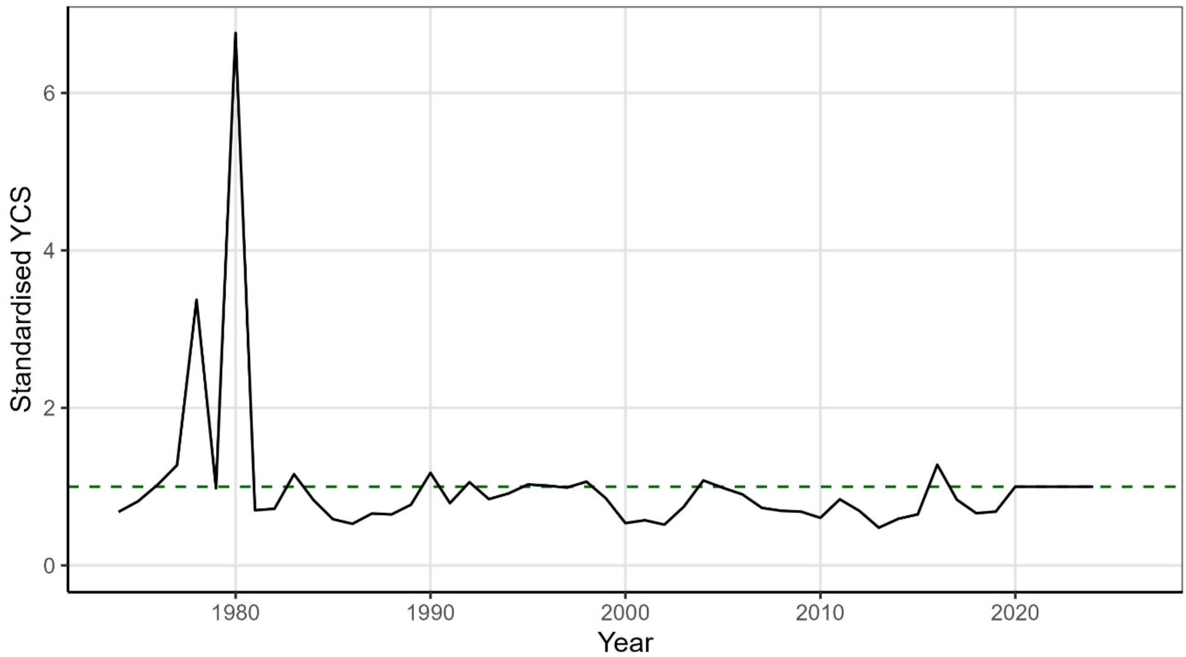

Figure 18: Base case model MPD estimates of the relative year class strength parameters; estimated for 1974–2019 and assumed equal to 1 for 2020 to 2024.

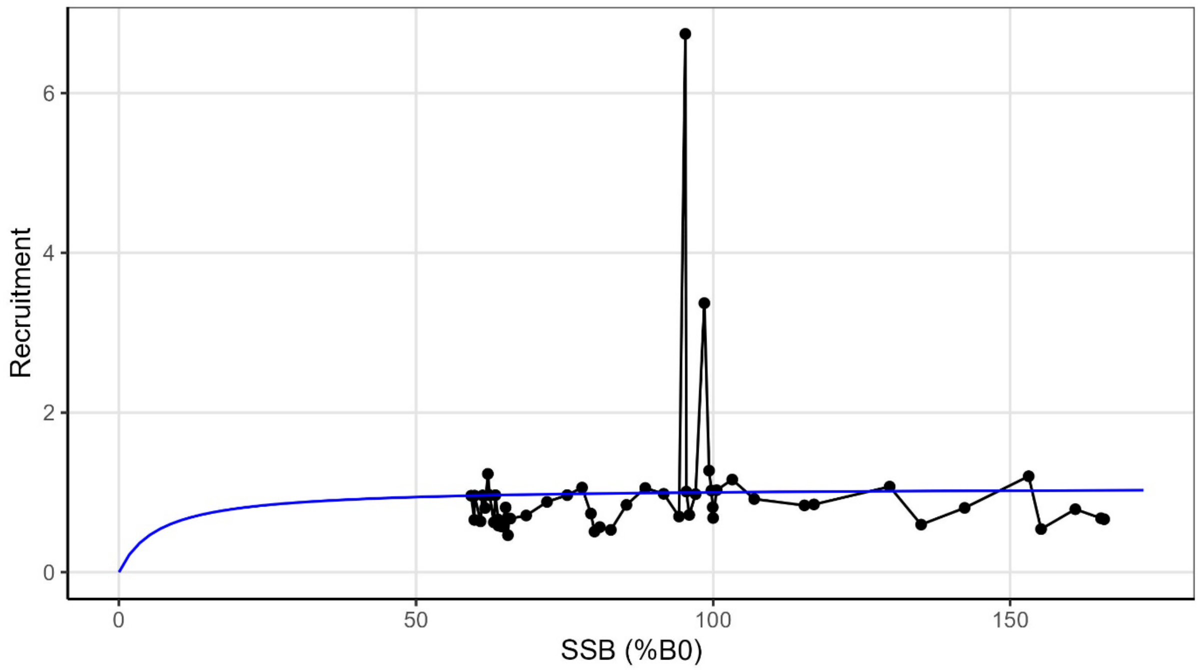

Figure 19: The stock recruitment relationship (Beverton-Holt with steepness *h* = 0.84), and the relative recruitment values (y-axis) plotted against *SSB* (x-axis) for the base case model.

3.3. MPD model retrospectives

Retrospective analyses of the base case model (R2.4) were carried out. This sequentially removed each year's catch and observations and reduced the year classes that were estimated to exclude the most recent year. This was done for 12 iterations, i.e., a retrospective was run for the years 2013–2025 and compared with the full model in 2025. Models were refitted at MPD and the resulting SSB trajectories are given in Figure 20 with the year class strength estimates in Figure 21. In general, the retrospective models were consistent with a slight reduction in the estimated B_0 in successive iterations as each additional recent year class was estimated at below average. Model predictions were similar within small clusters of about two or three years, perhaps linking with the biennial survey frequency.

Importantly, while the model assumed that the most recent year class strengths were initially equal to average, successive years estimated these as low as the additional age-composition observations were included (Figure 21), suggesting that as each new survey point was added, the model updated the estimates of YCS to fit the new survey observation and this then resulted in a reduced estimate of the current stock status (i.e., current SSB as a percent of B_0).

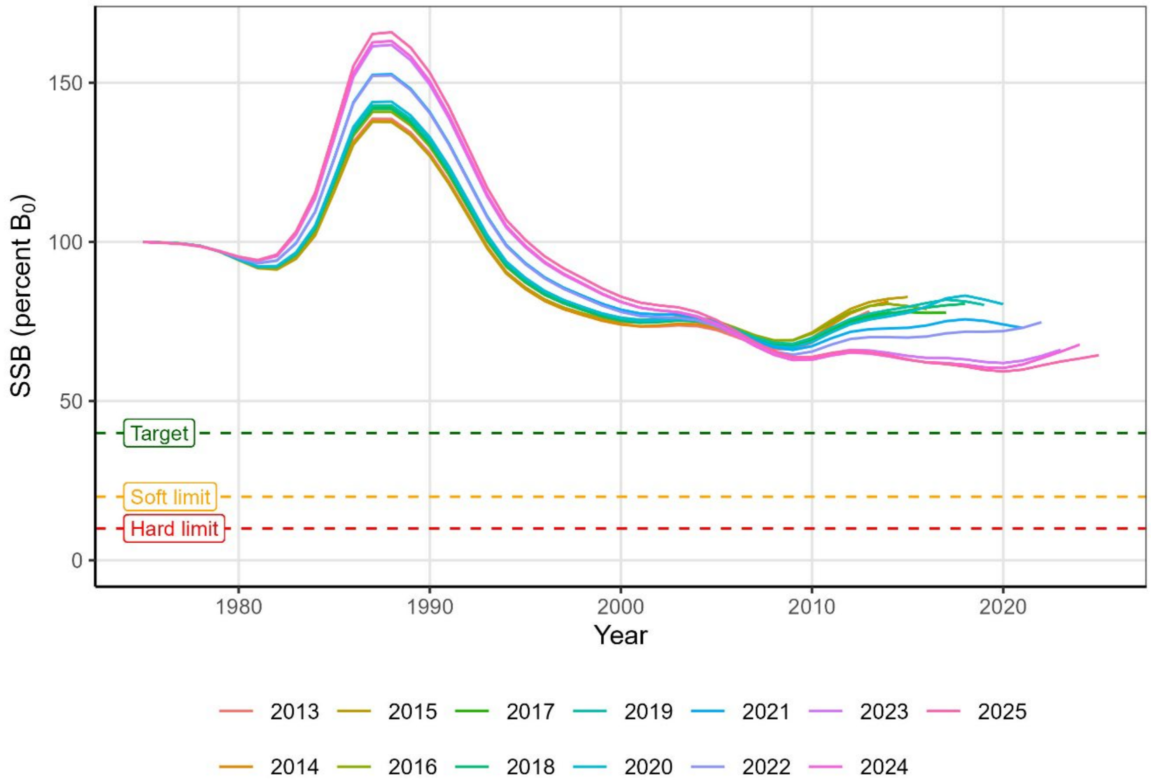

Figure 20: MPD retrospectives of SSB for the base case model (R2.4) for 2013–2025 (each line indicates an MPD fit to the model while excluding one additional year of data).

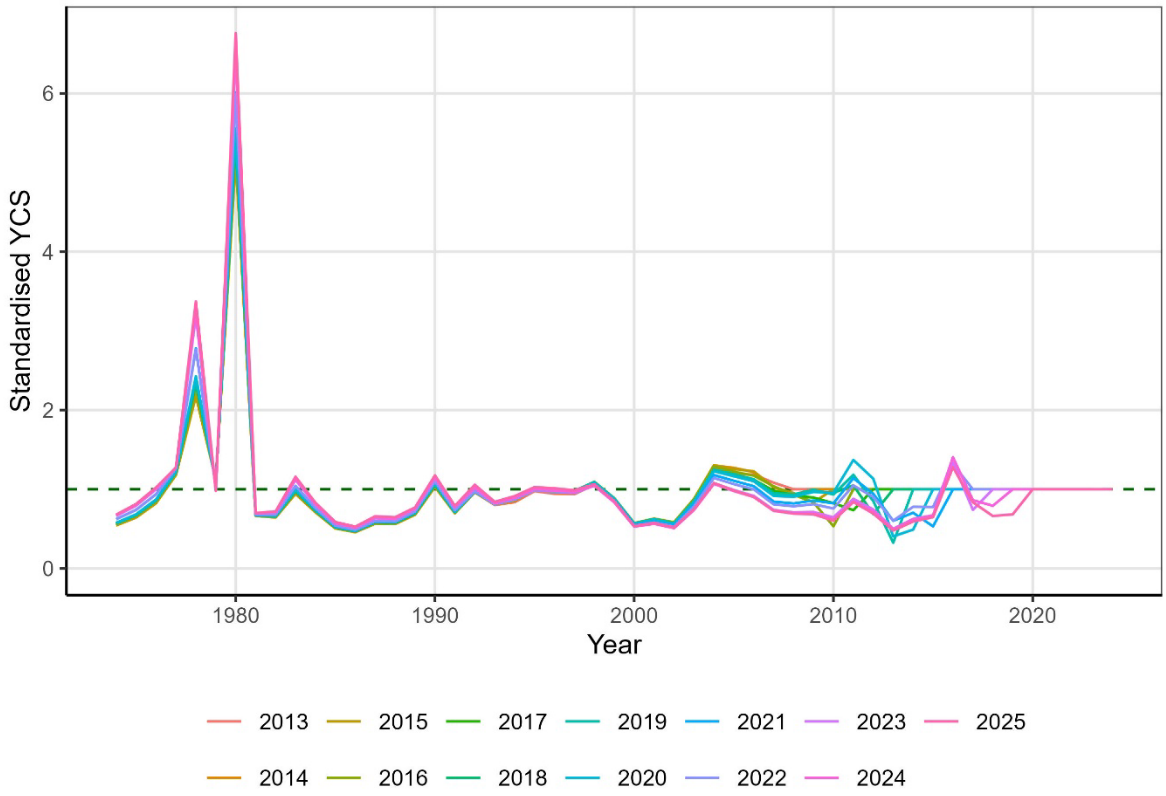

Figure 21: MPD retrospectives of YCS for the base case model for 2013–2025 (each line indicates an MPD fit to the model while excluding one additional year of data).

3.4. Model sensitivity analyses

Sensitivity analyses were carried out where the assumptions or choices of model observations might impact the outputs and conclusions (Table 8). These included evaluation of an assumption of lower (M=0.15 y^{-1}) and higher (M=0.23 y^{-1}) natural mortality; applying an informed prior on the survey catchability coefficients (q); including the Nov-Dec 2016 survey biomass estimate; including fishery age compositions for 1991–1993; splitting the fishery into two areas, using a 'fleets-as-areas' model based on the k=2 strata identified in Dunn et al. (2025); setting the additional process error CV for the surveys at zero; up-weighting and down-weighting the fishery and survey age compositions data relative to the biomass observations; and replacing the survey observations (both the Nov-Dec and Apr-May series) with a CPUE index for the fishery.

Overall, the sensitivity analyses did not suggest any significant departure from the MPD model estimates (Table 10). Most runs suggested a similar initial and current status as the base case, except for the models that fixed natural mortality at either a higher or lower value.

Table 10: Sensitivity models (MPD) to the 2025 base case stock assessment model for Sub-Antarctic hake for 2021 and current (2025) status.

Model		B_0	B_{2021}	B_{2021} (% B_0)	B_{2025}	B_{2025} (% B_0)
R1.1	2021 base case (updated in Casal2)	60 180	36 370	60.4	–	–
R5.0	2025 base case	74 055	44 324	59.9	47 684	64.4
R5.1	2025 base case with high *M*	152 909	94 826	62.0	101 184	66.2
R5.2	2025 base case with low *M*	56 967	32 236	56.6	34 859	61.2
R5.3	With informed prior on the survey catchability	72 061	42 391	58.8	45 633	63.3
R5.4	Including 1991–1993 fishery age compositions	72 035	44 928	62.4	48 334	67.1
R5.5	Including Nov-Dec 2016 survey biomass	73 924	44 141	59.7	47 489	64.2
R5.6	2025 base with 2 fleets as-areas	69 674	41 156	59.1	45 358	65.1
R5.8	2025 base case with no survey process error CV	74 271	45 358	61.1	48 158	64.8
R6.1	2025 base case with up-weighted age data	74 444	43 932	59.0	47 539	63.9
R6.2	2025 base case with down-weighted age data	72 136	45 081	62.5	47 447	65.8
R7.1	2025 base case with h = 0.66	74 511	44 108	59.2	47 266	63.4
R7.2	2025 base case with h = 0.5	75 597	43 887	58.1	46 692	61.8
R7.7	2025 base case with CPUE	73 238	52 183	71.3	56 898	77.7
R8.0	2025 base+	76 303	45 621	59.8	49 108	64.4

3.5. MCMC results

MCMCs were carried out for the base case and the sensitivity runs. Similar results were obtained for the MCMC estimates as for the equivalent run at MPD. Estimates of initial biomass (B_0), current biomass (B_{2025}), and current status (B_{2025} as a percent of B_0) are given in Table 11. Estimates of catchability parameters are given in Table 12.

MCMC estimates of year classes were uncertain in the initial years, but replicated the pattern seen in the MPDs of large year class strengths in the late 1970s and 1980 and average with low variability thereafter (Figure 22). Model estimates of initial biomass and current biomass were relatively symmetric, and comparisons of MCMC chains did not indicate any evidence of non-convergence (Figure 23).

Estimates of the trawl survey catchability (Figure 24) were within the priors but were concentrated at the bottom end of the prior, indicating low catchability of the surveys. Expected MCMC values for the *Tangaroa* survey biomass indices (Figure 25) were reasonable and the posterior predictive plots indicated a good fit of the MCMCs to the abundance biomass data. Estimated r-hat values for MCMC convergence were all below 1.05 (Figure 26).

Model estimates of the selectivity parameters (Figure 27) indicated good evidence that the relative selectivity of males and females differed in the survey and in the fishery.

The base case model suggested an initial spawning stock biomass of 72 600 t (95% C.Is. 60 200–93 800 t) and current biomass of 47 000 t (95% C.I.s 33 200–70 400 t), with a current status of 65% (95% C.I.s 52–79%) (Figure 28).

Table 11: Estimates (t) of B_0 and current status for the base case and sensitivity runs for the Sub-Antarctic hake assessment model.

Model		B_0	B_{2025}	B_{2025} (% B_0)
R1.1	2021 base case (updated in Casal2)	78 870 (74 140–84 810)	30 350 (22 450–43 390)	38.6 (29.5–52.2)
R5.0	2025 base case	72 577 (60 157–93 766)	47 023 (33 165–70 417)	64.8 (52.3–79.0)
R5.1	2025 base case with high *M*	137 022 (94 133–213 689)	87 506 (52 184–152 746)	63.7 (52.4–77.0)
R5.2	2025 base case with low *M*	57 120 (50 368–66 078)	34 633 (25 825–46 935)	60.6 (49.6–73.2)
R5.3	With informed prior on the survey *q*	70 587 (58 942–88 866)	45 103 (31 877–65 551)	63.8 (51.7–78.1)
R5.4	Including 1991-1993 fishery ages	72 157 (58 649–94 239)	47 530 (32 949–71 288)	65.7 (53.5–79.9)
R5.5	Including Nov-Dec 2016 survey	72 671 (59 881–92 639)	47 124 (32 830–69 140)	64.9 (52.2–78.8)
R5.6	2025 base with 2 fleets as-areas	67 339 (55 715–85 871)	43 877 (30 738–64 748)	65.3 (53.0–79.4)
R5.8	With no survey process error CV	72 751 (60 526–92 594)	47 147 (34 669–67 478)	64.8 (54.2–76.7)
R6.1	With up-weighted age data	73 858 (64 043–88 575)	47 161 (35 438–64 377)	63.9 (53.6–75.5)
R6.2	With down-weighted age data	72 035 (56 355–100 791)	46 684 (31 389–75 095)	64.6 (52.2–79.3)
R7.1	2025 base case with *h* = 0.66	73 116 (60 374–94 337)	46 891 (32 515–69 992)	64.3 (51.7–78.2)
R7.2	2025 base case with *h* = 0.5	74 362 (62 051–96 758)	46 439 (32 431–71 090)	62.6 (49.7–76.4)
R7.7	2025 base case with CPUE	54 759 (46 366–74 479)	30 737 (21 950–48 349)	55.7 (45.6–69.4)
R8.0	2025 base+	74 668 (61 852–94 845)	48 317 (33 709–69 902)	64.7 (52.3–78.1)

Table 12: Estimates of Nov-Dec and Apr-May survey catchability (*q*) estimates for the base case and sensitivity runs for the Sub-Antarctic hake assessment model.

Model		Nov-Dec survey *q*	Apr-May survey *q*
R5.0	2025 base case	0.035 (0.025–0.045)	0.056 (0.038–0.085)
R5.1	2025 base case with high *M*	0.018 (0.011–0.027)	0.030 (0.018–0.050)
R5.2	2025 base case with low *M*	0.058 (0.047–0.071)	0.071 (0.051–0.103)
R5.3	With informed prior on the survey *q*	0.036 (0.028–0.046)	0.059 (0.041–0.090)
R5.4	Including 1991-1993 fishery ages	0.035 (0.026–0.045)	0.058 (0.039–0.089)
R5.5	Including Nov-Dec 2016 survey biomass	0.035 (0.026–0.045)	0.056 (0.039–0.084)
R5.6	2025 base with 2 fleets as-areas	0.038 (0.028–0.049)	0.065 (0.044–0.099)
R5.8	With no survey process error CV	0.034 (0.026–0.043)	0.055 (0.039–0.077)
R6.1	With up-weighted age data	0.036 (0.028–0.043)	0.051 (0.039–0.067)
R6.2	With down-weighted age data	0.034 (0.023–0.046)	0.058 (0.035–0.104)
R7.1	2025 base case with *h* = 0.66	0.035 (0.026–0.046)	0.057 (0.039–0.086)
R7.2	2025 base case with *h* = 0.5	0.035 (0.025–0.046)	0.056 (0.038–0.083)
R7.7	2025 base case with CPUE	0.205 (0.024–0.383)	0.211 (0.026–0.384)
R8.0	2025 base+	0.034 (0.025–0.044)	0.055 (0.037–0.081)

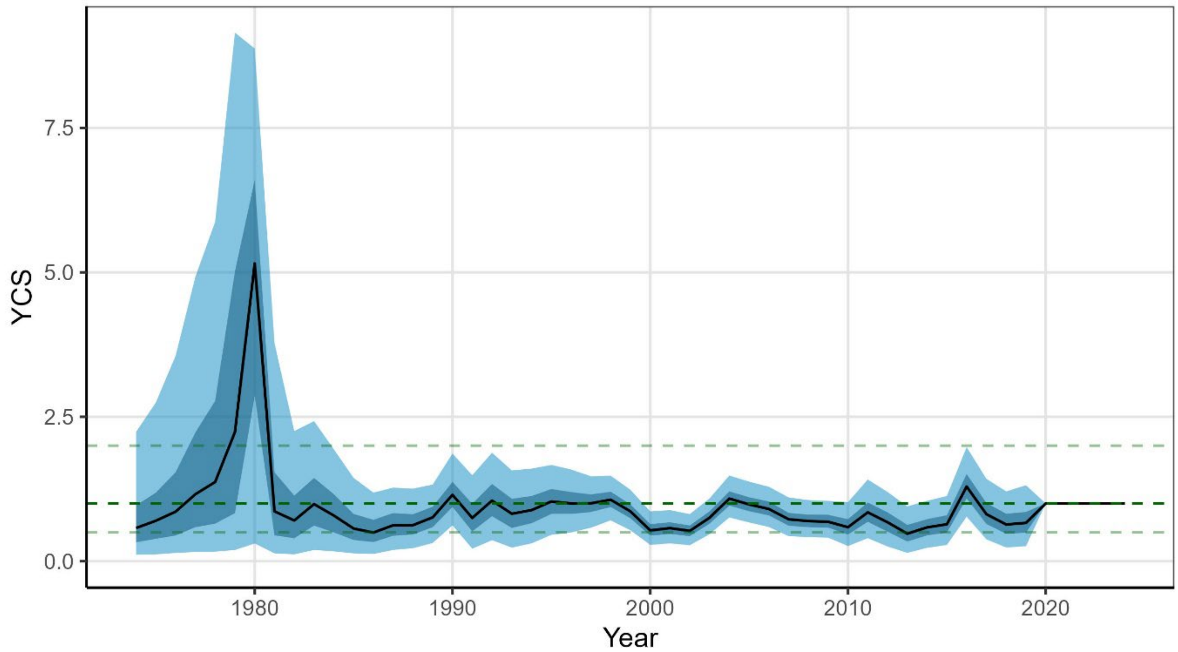

Figure 22: Base case model posterior distribution of year class strengths for years 1974–2019. The points indicate the median and the shaded area represents the 95% credible intervals. The dotted horizontal line indicates the average of one.

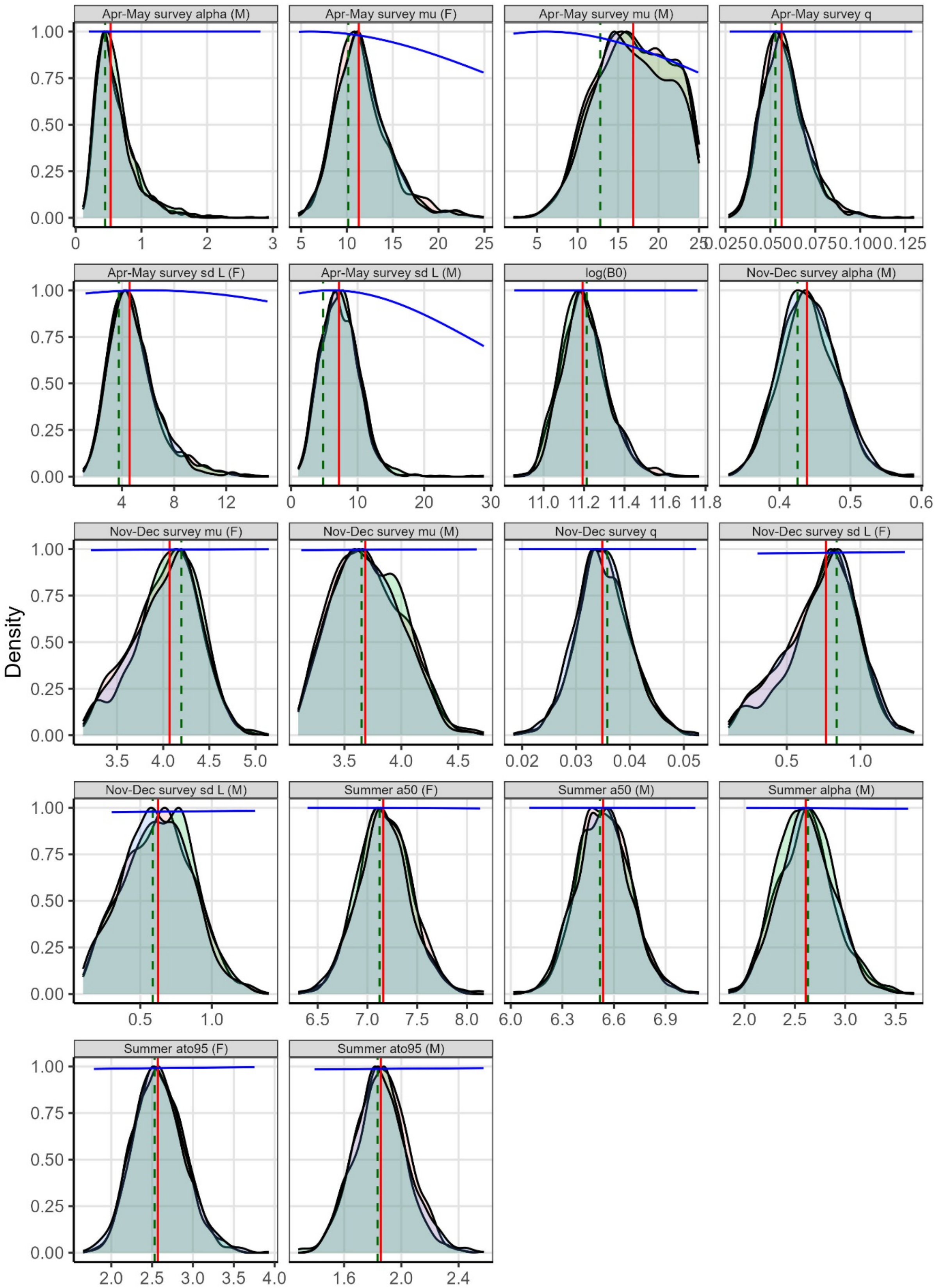

Figure 23: Base case model posterior distributions of estimated parameters (excluding YCS) for each of the three chains (labelled 1–3), Priors over the range of estimated posterior values are shown as the blue lines, and the median MCMC estimate as the vertical red lines and the MPD (also the starting point for MCMCs) as the dashed green lines.

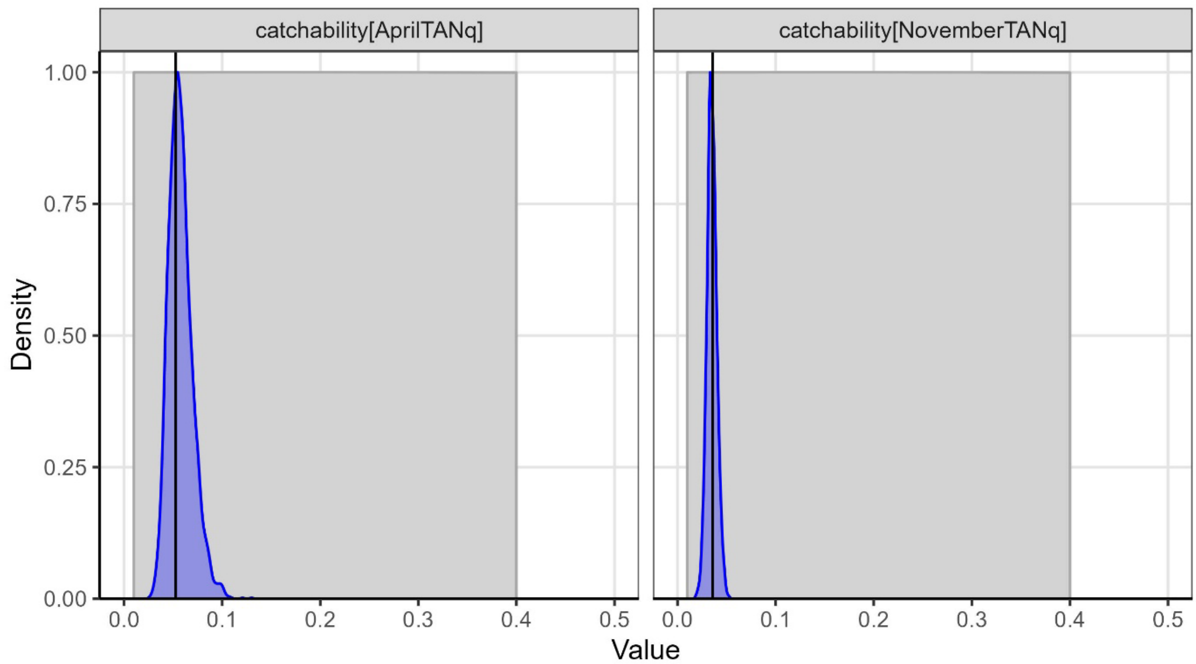

Figure 24: Base case model posterior distributions of the *Tangaroa* series catchability (purple) and the corresponding non-informative prior (grey).

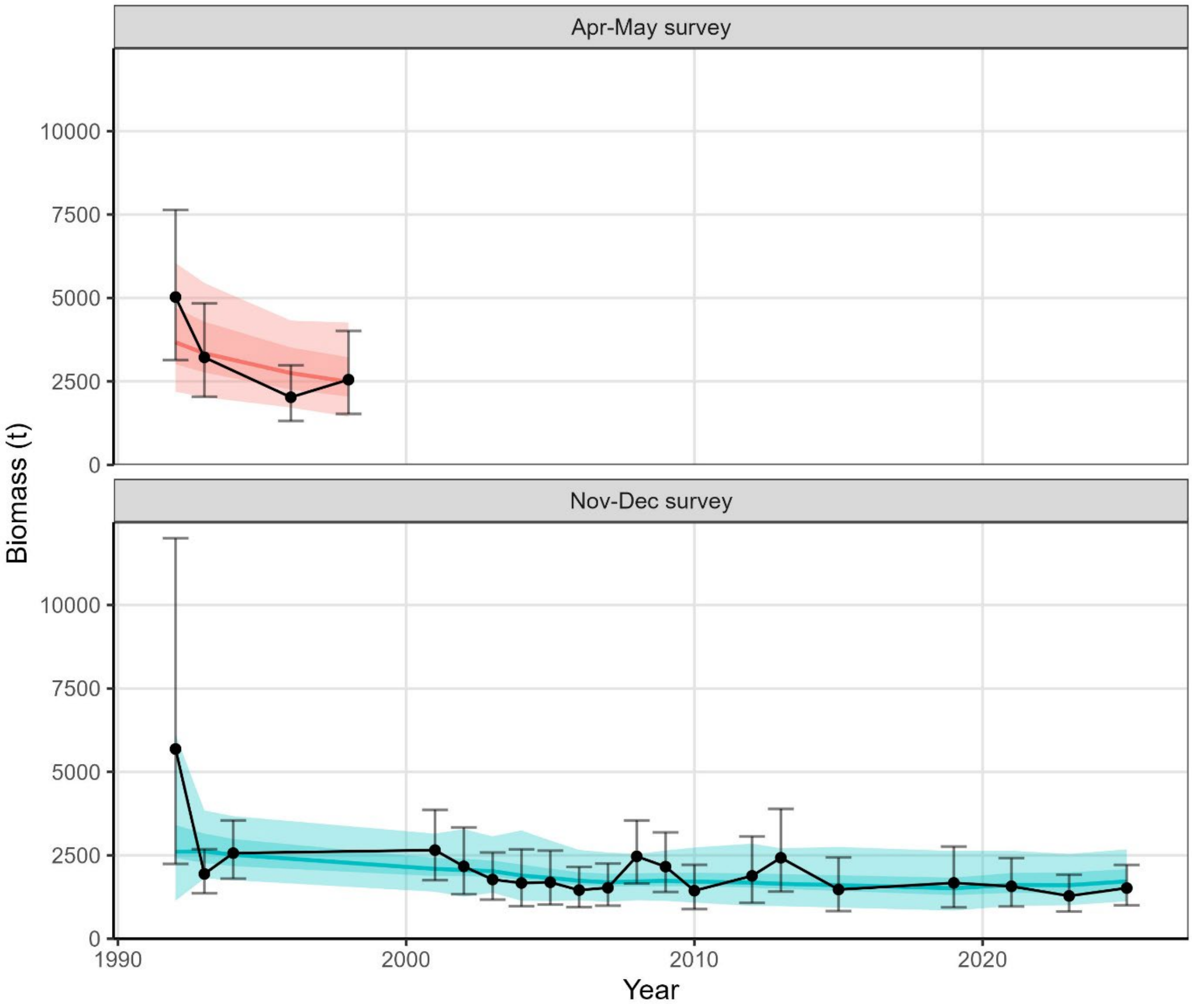

Figure 25: Base case model posterior plots of the expected values for the (top) Apr-May and (bottom) Nov-Dec *Tangaroa* survey series. Observed values (and 95% confidence intervals) are shown as vertical lines. The dark shaded region indicates the 95% credible intervals for the estimated mean and the light shaded region indicates the 95% credible intervals for the posterior predictive distribution.

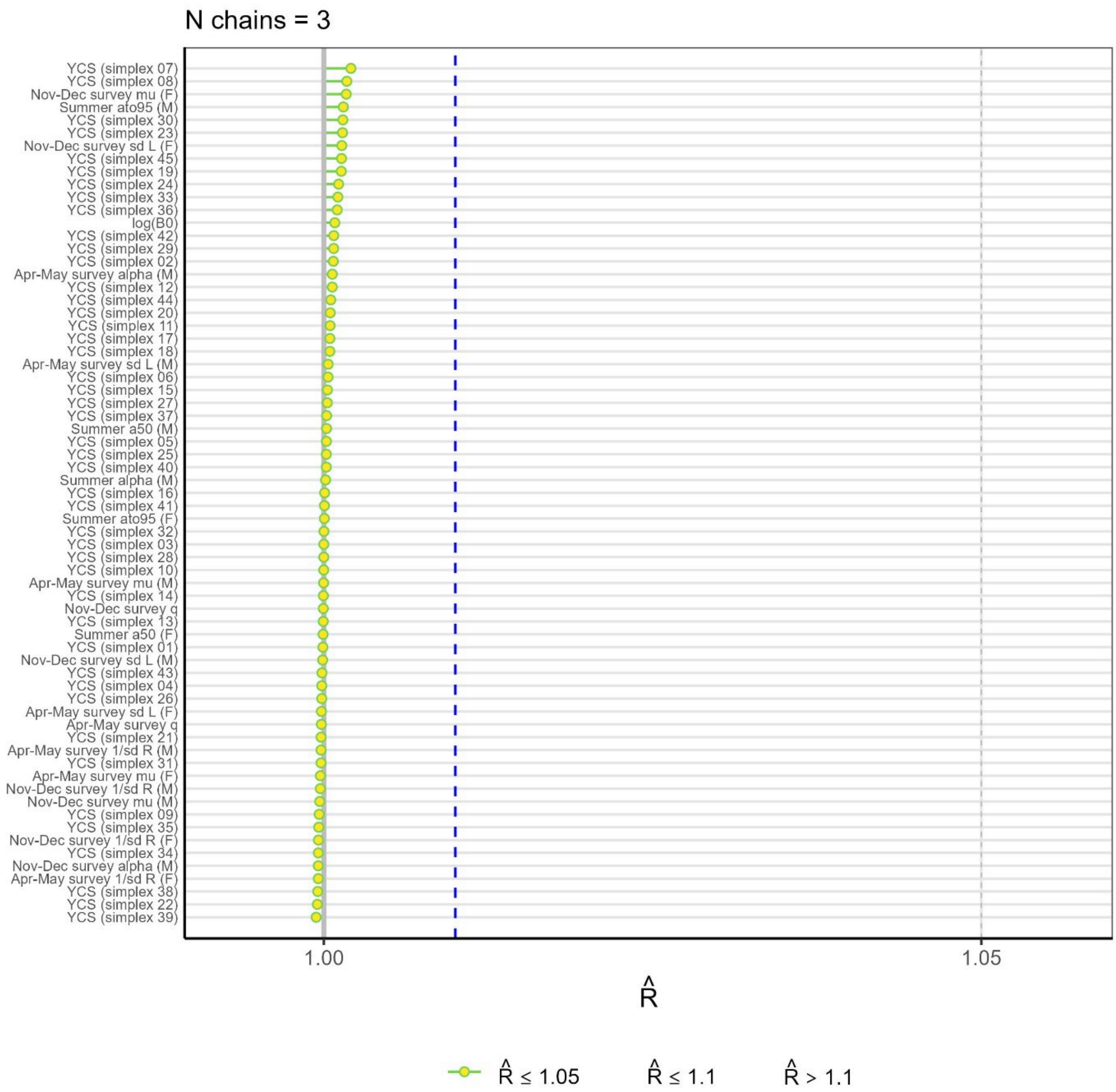

Figure 26: Base case model MCMC $\hat{r}$ statistics for all parameters from the three independent chains ($\hat{r}$ values less than 1.01 suggest no evidence of non-convergence).

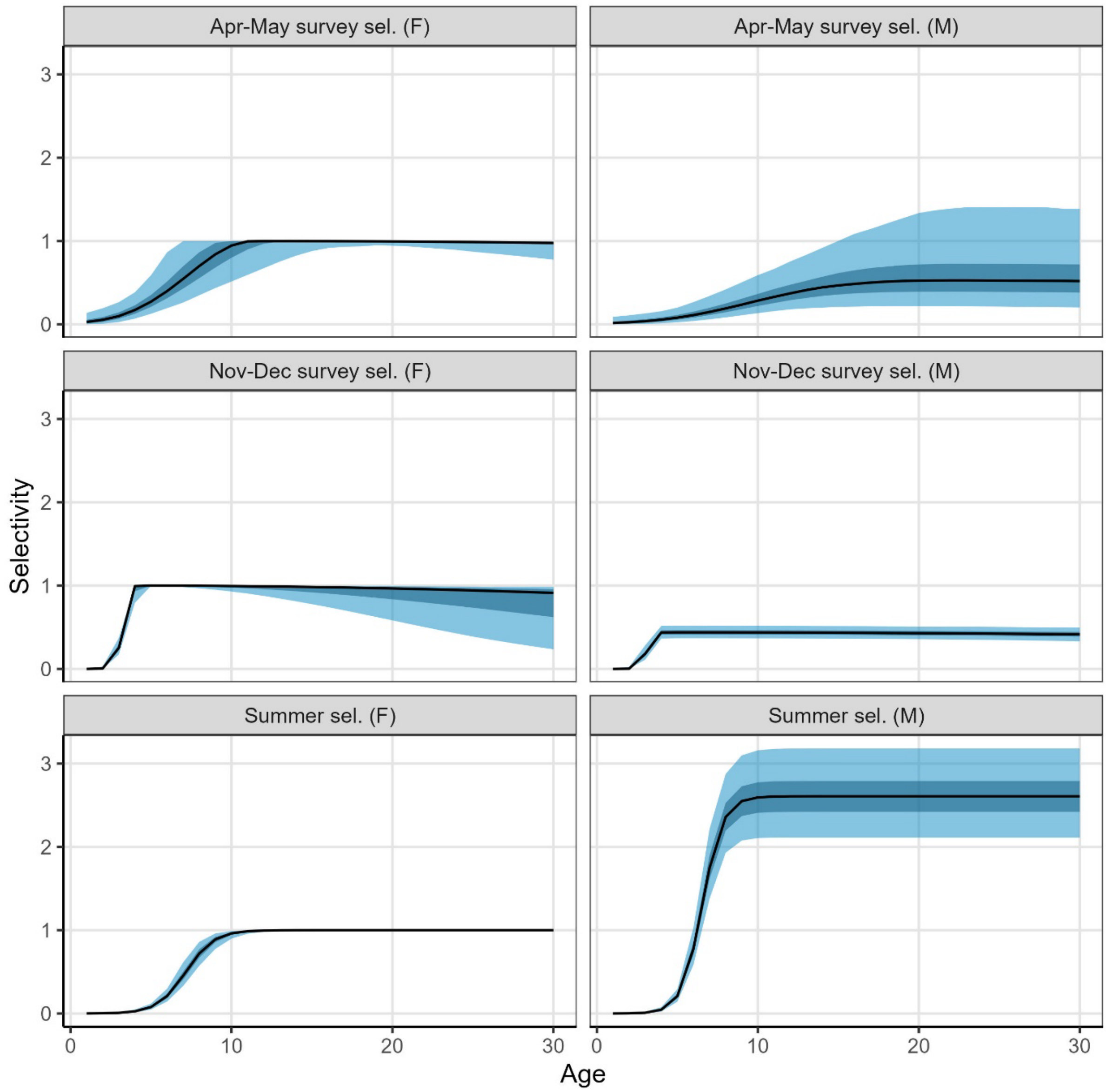

Figure 27: Base case model posterior distribution of the expected values for the (top) Apr-May and (middle) Nov-Dec *Tangaroa* survey series; and (bottom) fishery selectivities for males (left) and females (right). The solid line indicates the median trajectory, and the dashed lines indicate the 95% credible intervals.

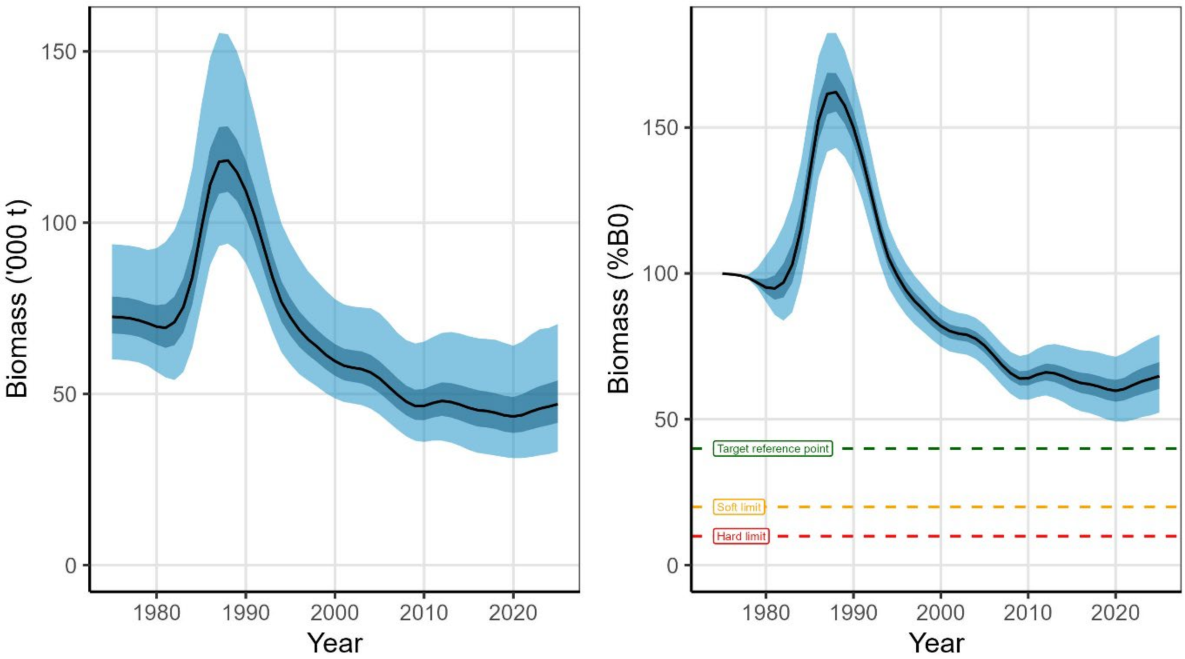

Figure 28: Posterior distribution of the historical (1975–2025) stock biomass (t) for the base case model for Sub-Antarctic hake. The solid line indicates the median trajectory and the shaded area indicates the 95% credible interval.

3.6. Alternative catch history

A plausible alternative catch history for hake that included possible unreported catches and an estimate of discards and small fish mortality resulting from escapement through the fishing net mesh was developed. Data on small fish catch and likely mortality from escapement through net mesh is not known for hake. However, the level of unreported catch prior to the introduction of the Quota Management System (QMS) in 1986 is assumed to be low due to the high commercial value of hake, and hence the fishers are likely to have retained as much catch as possible during that time. More recently, discards are thought to be low—discards from the hoki, hake, and ling (*Genypterus blacodes*) target trawl fishery within the New Zealand EEZ were estimated by Anderson et al. (2019) as 0.42%.

Given the likely low proportions of under-reporting of hake, an approximation that assumed 10% additional fishery mortality for years before the introduction of the QMS, 5% in the years up to 2000, and 2% thereafter was run to investigate sensitivity to the base case model (base+ model). The inclusion of the assumption of additional mortality and pre-QMS unreported catch resulted in estimates of biomass that were only slightly different to the base case above (Figure 29).

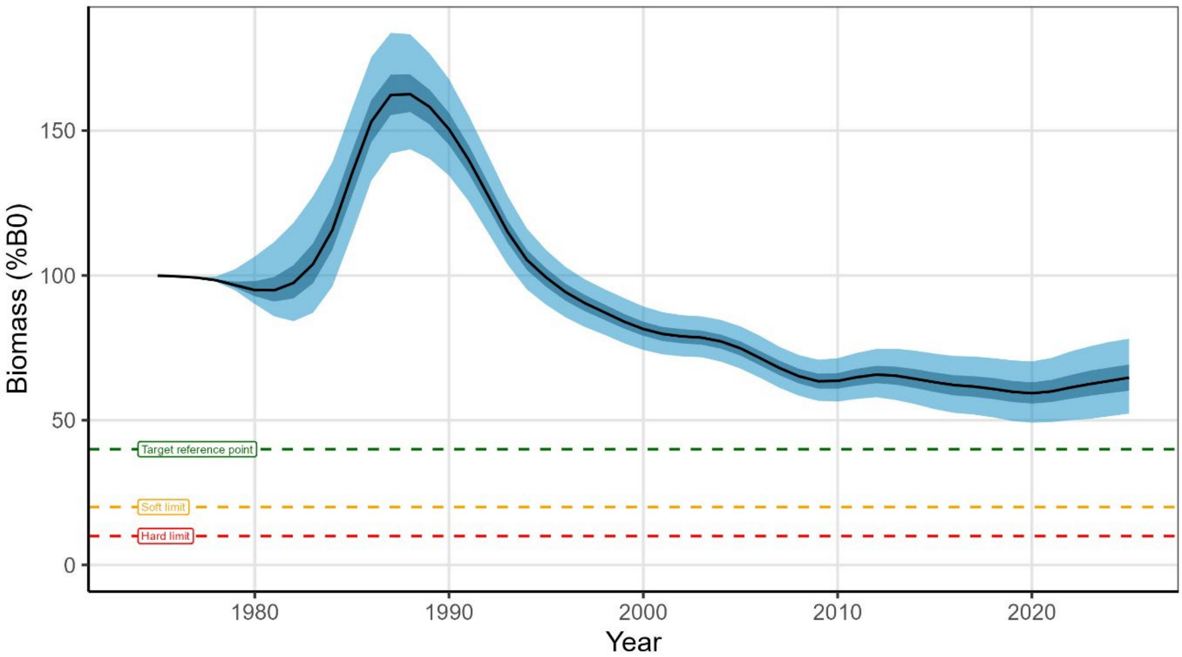

Figure 29: The base+ MCMC stock status trajectory (% B_0) for 1974–2025. The solid line indicates the median trajectories, and the shaded areas indicate the 95% credible intervals. Horizontal lines indicate the target (green, 40% B_0), soft limit (yellow, 20% B_0), and hard limit (red, 10% B_0), respectively.

3.7. Projections

Four sets of projection runs were carried out where the future annual catch for the next three years was set at the level of the current catch (1084 t) or the current TACC for HAK 1 (3701 t). The catch split between the summer and winter fisheries was based on the average catch split for the most recent five years of reported catches (2019–2024).

Results are shown in Table 13 for the estimated stock status, and in Table 14 for risks of being below target, soft, or hard limits. Figure 30 shows the *SSB* trajectories under the assumption of current catch and recent year class strengths projected for three years into the future, and Figure 31 shows the same projection as percent of B_0. Stock status in 2028 is expected to either stay the same or decrease slightly over the next three years under assumptions of both current catch and a catch equal to the HAK 1 TACC and recent recruitment. With long term average recruitment, the status is expected to increase under both catch scenarios.

Table 13: Estimates of B_0 (t) and 95% credible intervals for the estimated projected status (B_{2028} in tonnes or as a percent of B_0) for 2025 and 2028 for the base case and selected sensitivity runs for Sub-Antarctic hake, with assumptions of future recruitment either equal to the average over all years, or the most recent 10 years; and assuming future catch equals either current catch (1084 t) or the TACC (3701 t).

Future catch (t)	Future YCS	B_{2025}	B_{2028}	B_{2028} (% B_0)
1. Base case				
1 084	2010–2019	46 269 (32 039–70 057)	45 781 (30 168–72 765)	63.1 (47.7–83.2)
3 701		46 269 (32 039–70 057)	40 498 (24 886–67 436)	55.8 (39.5–76.5)
1 084	1974–2019	46 909 (32 782–70 945)	49 855 (32 899–88 541)	67.5 (51.3–115.3)
3 701		46 909 (32 782–70 945)	44 576 (27 637–83 268)	60.4 (43.4–108.1)
3. Low *M*				
1 084	2010–2019	34 260 (25 387–46 929)	34 378 (24 136–48 838)	60.3 (46.1–77.9)
3 701		34 260 (25 387–46 929)	28 839 (18 590–43 328)	50.5 (35.6–69.0)
1 084	1974–2019	34 531 (25 668–47 371)	36 192 (25 967–57 274)	63.0 (49.3–97.3)
3 701		34 531 (25 668–47 371)	30 653 (20 446–51 747)	53.4 (39.0–87.9)
4. High *M*				
1 084	2010–2019	84 898 (49 691–149 249)	83 341 (46 509–152 164)	60.2 (45.7–79.7)
3 701		84 898 (49 691–149 249)	78 294 (41 485–147 117)	56.6 (41.0–76.6)
1 084	1974–2019	87 089 (51 110–153 950)	89 690 (46 972–198 763)	63.4 (45.6–129.8)
3 701		87 089 (51 110–153 950)	94 741 (52 036–203 726)	66.9 (49.8–134.1)

Table 14: Estimated projected probability of being below the target (40% B_0) or the soft or hard limits (20% or 10% B_0, respectively) in 2028, for the base case and selected sensitivity models for Sub-Antarctic hake, with assumptions of future recruitment either equal to the average over all years, or the most recent 10 years; and assuming future catch equals either current catch (1084 t) or the TACC (3701 t). YCS is year class strength.

Future catch (t)	Future YCS	P(>40%)	P(<20%)	P(<10%)
1. Base case				
1 084	2010–2019	>0.99	0.00	0.00
3 701		0.97	0.00	0.00
1 084	1974–2019	>0.99	0.00	0.00
3 701		>0.99	0.00	0.00
3. Low *M*				
1 084	2010–2019	>0.99	0.00	0.00
3 701		0.90	0.00	0.00
1 084	1974–2019	>0.99	0.00	0.00
3 701		0.96	0.00	0.00
4. High *M*				
1 084	2010–2019	>0.99	0.00	0.00
3 701		>0.99	0.00	0.00
1 084	1974–2019	>0.99	0.00	0.00
3 701		>0.99	0.00	0.00

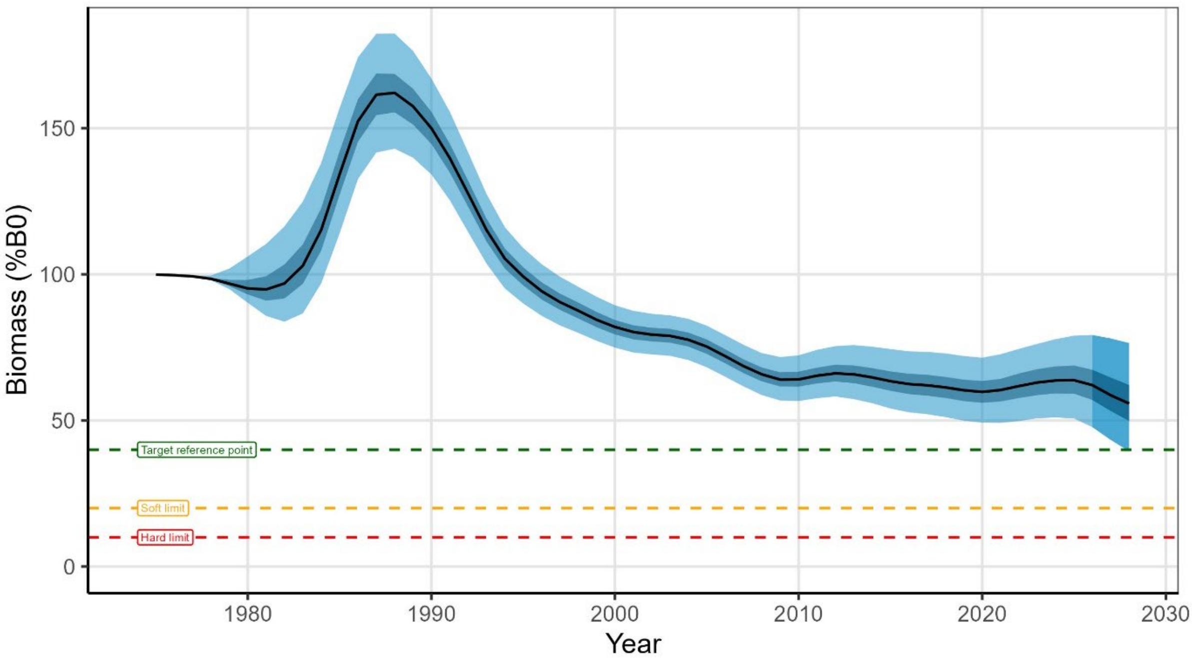

Figure 30: Posterior distribution of the historical (1975–2025, light shading) and projected (2026–2028, dark shading) stock biomass for the base case model for Sub-Antarctic hake assuming the TACC and recent recruitment. The solid line indicates the median trajectories, and the shaded areas indicate the 95% credible intervals. Horizontal lines indicate the target (green, 40% B_0), soft limit (yellow, 20% B_0), and hard limit (red, 10% B_0), respectively.

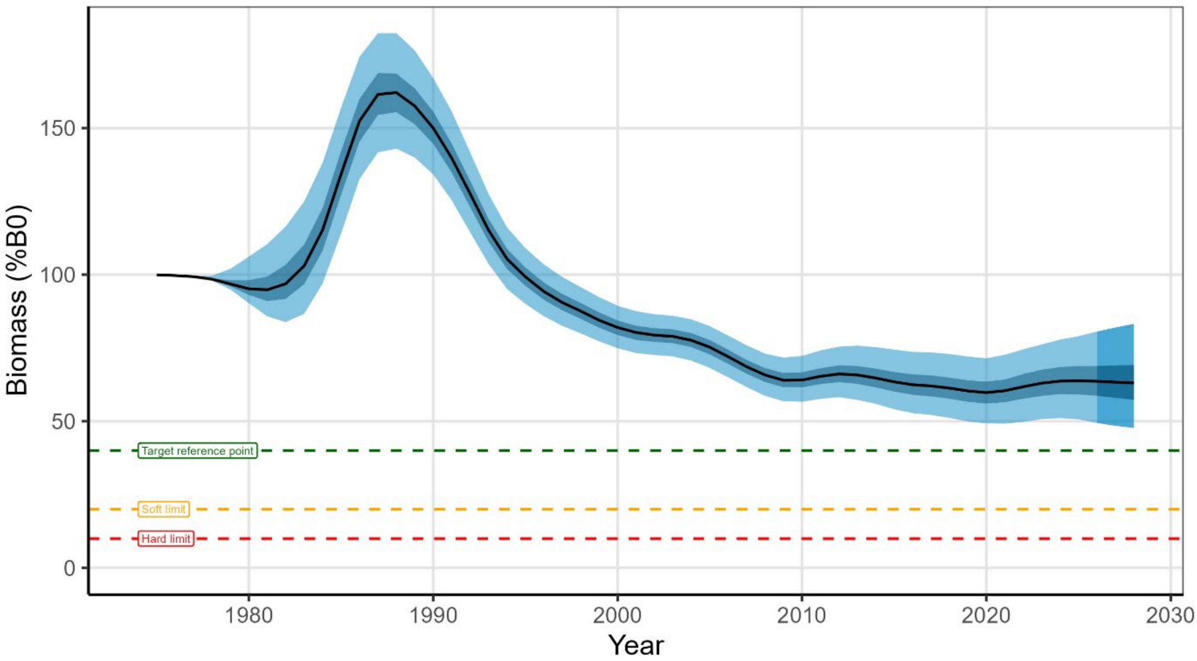

Figure 31: Posterior distribution of the historical (1975–2025, light shading) and projected (2026–2028, dark shading) stock biomass as a percent of B_0 for the base case model for Sub-Antarctic hake assuming current catches and recent recruitment. The solid line indicates the median trajectories, and the shaded areas indicate the 95% credible intervals. Horizontal lines indicate the target (green, 40% B_0), soft limit (yellow, 20% B_0), and hard limit (red, 10% B_0), respectively.

4. DISCUSSION

The initial stock assessment model for Sub-Antarctic hake in HAK 7 presented here was developed from the 2021 assessment (Dunn et al. 2021b). That assessment concluded that the spawning stock was above the target, and that at the then current catch levels the stock was likely to remain stable.

This assessment updated the previous model with new observations made since the previous assessment, including updated survey indices and sex-based age compositions. The assessment was also migrated from CASAL to Casal2, with comparisons showing good agreement between the two platforms. This assessment suggested that while the stock biomass was higher than previously estimated, the stock status remained very similar to previous assessments.

The base case model estimated an initial spawning stock biomass of 72 600 t (95% credible intervals 60 200–93 800 t) and current biomass of 47 000 t (95% credible intervals 33 200–70 400 t), with a current status of 65% B_0 (95% credible intervals 52–79% B_0).

The assumption that the Sub-Antarctic stock (including Puysegur Bank) is a single stock remains an uncertainty—specifically the stock affinity of hake in the Puysegur Bank area. However, the association of Puysegur hake with the Sub-Antarctic remains the most parsimonious interpretation of available information.

The trawl survey biomass indices provided the most information to the model, with the November-December series showing a gradual decline from the early 1990s to around 2015, followed by relatively stable biomass through to 2025. The age composition data from both surveys and commercial fisheries were consistent with the estimated recruitment patterns, showing evidence of stronger year classes in the early 1980s followed by generally below-average recruitment with low variability.

Assessment model sensitivity runs did not suggest that alternative assumptions would lead to significantly different outcomes. Natural mortality sensitivity runs showed the expected inverse relationship with biomass estimates, while variations in steepness, survey catchability priors, and data weighting had minimal impact on stock status estimates. MCMC diagnostics were reasonable for all estimated parameters, with $\hat{r}$ values below 1.05 indicating good convergence.

Model projections suggested that under current catch levels (approximately 1084 t annually), the biomass of hake in the Sub-Antarctic would be likely to remain stable or increase slightly over the next three years. Even under the higher catch scenario equal to the current TACC for HAK 1 (3701 t), the stock would remain well above management reference points, although with some decline toward the target biomass of 40% B_0 if recent lower recruitment levels continue.

The retrospective analysis revealed a consistent pattern where successive assessments estimated recent year class strengths as below average once additional survey data became available, as well as higher early YCS peaks than before. This suggests that the assumption of average recruitment for the most recent years may be optimistic, and projections based on recent recruitment patterns may provide more realistic expectations for stock trajectory.

Pinkerton et al. (2018, 2023) proposed methods for a qualitative evaluation of potential effects of environmental or climate change on the stock assessment, and a summary of the qualitative evaluation determined by the Deepwater Working Group is given in Dunn et al. (2025). The evaluation did not result in identifying any significant changes that would need to be considered in the scientific advice of stock status or in the stock projections.

The inclusion of potential additional mortality to account for unreported catch and discards (base+ model) had minimal impact on stock status estimates, suggesting that the base case catch history adequately represents the fishing mortality experienced by the stock.

Reference points for hake on the Sub-Antarctic have a management target of 40% B_0, a soft limit of 20% B_0, and a hard limit of 10% B_0. The overfishing threshold was assumed to be $F_{40\%B_0}$, calculated as 0.16 using the base case model with recent year class strengths. B_{2025} was estimated to be virtually certain to be above the target for all sensitivity runs and exceptionally unlikely to be below the soft or hard limit. Overfishing is exceptionally unlikely to be occurring (Figure 32).

Based on the four projections carried out, the stock status is unlikely to change over the next five years at recent catch levels and therefore overfishing is exceptionally unlikely to manifest.

The estimates of additional, unreported fishing mortality of 10% before the introduction of the QMS, 5% for the years immediately following the QMS, and 2% thereafter are plausible, but highly uncertain. The inclusion of the additional mortality estimates did not significantly change the conclusions of the model or the management implications.

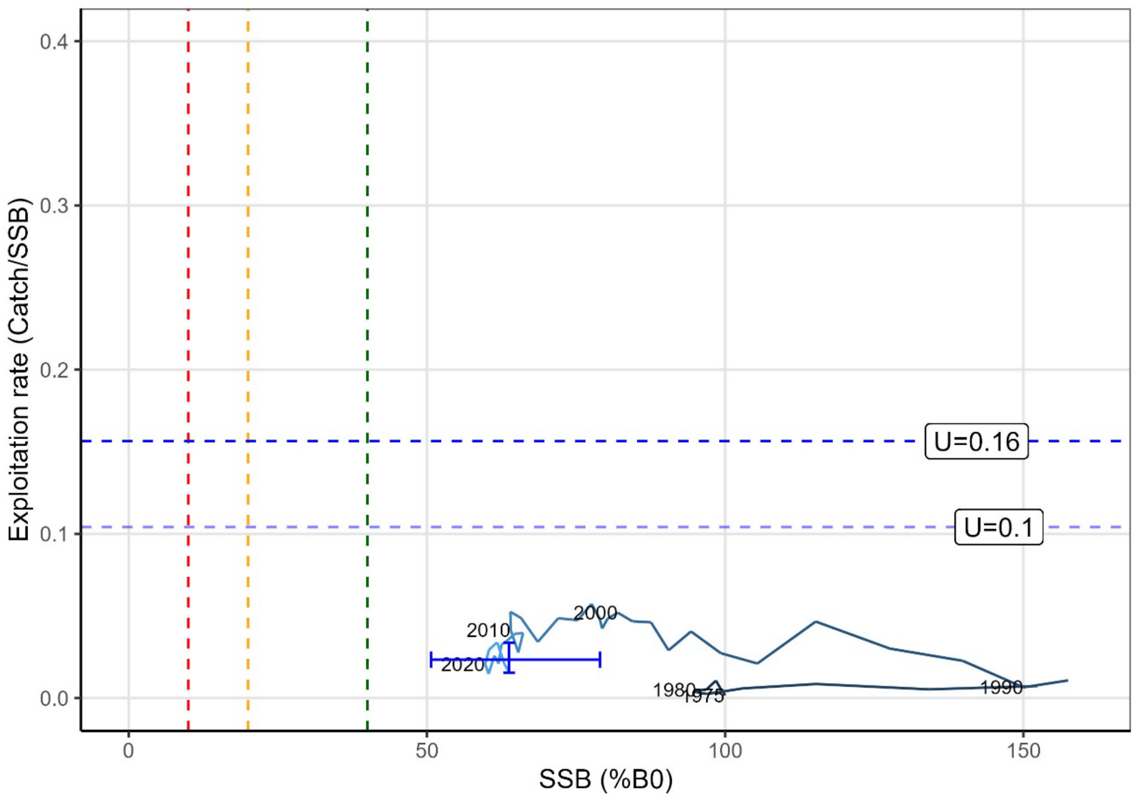

Figure 32: Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the base case model from the start of the assessment period in 1975, to 2025 (in blue). The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, green line is the % B_0 target (40% B_0) and the blue lines are the corresponding exploitation rate (U_{40} = 0.16 for all YCS and U_{40} = 0.10 for recent YCS). Biomass and exploitation rate estimates are medians from MCMC results. The blue cross represents the limits of the 95% credible intervals of estimated the ratio of the *SSB* to B_0 and exploitation rate in 2025.

5. FULFILMENT OF BROADER OUTCOMES

Whakapapa links all people back to the land, sea, and sky, and our obligations to respect the physical world. This research aims to ensure the long-term sustainability of hake stocks, for the good of the wider community (including stakeholders and the public) and the marine ecosystems that ling inhabit. This project supports Māori and regional businesses, diversity and inclusion, and our research is inextricably linked to the moana from the work it carries out and the tangata whenua it supports.

As part of this project, the team has continued to build capacity and capability in fisheries science and stock assessment, its commitment to zero waste and carbon neutrality, environmental stewardship and social responsibility.

6. ACKNOWLEDGEMENTS

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APPENDIX A: MPD SUMMARY TABLES

Table 15: MPD objective function values for the base case and sensitivity models.

	R5.0	R5.1	R5.2	R5.3	R5.4	R5.5	R5.6	R5.8	R6.1	R6.2	R7.1	R7.2	R7.7	R8.0
YCS: YCS	183.6	184.2	183.2	183.6	183.5	183.6	183.6	183.6	184.0	183.1	183.5	183.5	183.0	183.6
jacobian: Apr-May survey 1/sd R (M)	-9.6	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.6	-9.6	-9.5	-9.6
jacobian: Apr-May survey 1/sd R (F)	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.4	-9.6	-9.4	-9.4	-9.6
jacobian: Nov-Dec survey 1/sd R (F)	-6.5	-9.4	-5.5	-6.4	-9.4	-6.5	-9.4	-6.6	-6.2	-9.4	-6.4	-6.4	-9.5	-6.4
jacobian: Nov-Dec survey 1/sd R (M)	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.4	-9.5
jacobian: log(B0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
observation: Apr-May survey (AC)	91.3	90.9	92.7	91.3	91.1	91.3	90.1	91.3	182.4	45.7	91.3	91.3	91.9	91.3
observation: Apr-May survey	-4.1	-4.4	-3.7	-4.1	-4.0	-4.1	-4.1	-2.9	-2.9	-4.1	-4.1	-4.1	0.0	-4.1
observation: Nov-Dec survey (AC)	694.0	695.8	693.5	694.0	698.4	694.0	710.0	694.5	1386.5	349.0	694.1	694.4	691.1	693.9
observation: Nov-Dec survey	-19.9	-20.0	-19.8	-19.8	-20.0	-20.9	-19.9	-19.3	-18.3	-20.4	-19.9	-20.0	0.0	-19.8
observation: CPUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-26.4	0.0
observation: Summer (AC)	893.4	886.6	907.5	893.3	953.4	893.4	0.0	893.7	1787.0	446.8	893.4	893.5	1082.2	893.4
penalty: Catch penalty	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0
prior: Error multiplier (Apr-May survey AC)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	1.1	1.1	1.1	1.1	1.1	1.1
prior: Apr-May survey q	2.3	2.3	2.3	-2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
prior: Survey biomass process error	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	1.1	1.1	1.1	1.1	1.1	1.1
prior: Nov-Dec survey q	2.3	2.3	2.3	-1.8	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
prior: Apr-May survey 1/sd R (F)	3.7	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.7	3.7	3.5	3.7
prior: Apr-May survey 1/sd R (M)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.7	3.5	3.5	3.7
prior: Nov-Dec survey 1/sd R (F)	5.6	3.5	6.0	5.7	3.5	5.6	3.5	5.6	5.8	3.5	5.7	5.7	3.5	5.6
prior: Nov-Dec survey 1/sd R (M)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
prior: log(B0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Apr-May survey mu (F)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Apr-May survey sd L (F)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Apr-May survey alpha (M)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Apr-May survey mu (M)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Apr-May survey sd L (M)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Nov-Dec survey mu (F)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Nov-Dec survey sd L (F)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Nov-Dec survey alpha (M)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Nov-Dec survey mu (M)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Nov-Dec survey sd L (M)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Summer a50 (F)	3.4	3.4	3.4	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.7	3.4
prior: Summer ato95 (F)	3.4	3.4	3.4	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Summer a50 (M)	3.4	3.4	3.4	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Summer alpha (M)	3.4	3.4	3.4	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4
prior: Summer ato95 (M)	3.4	3.4	3.4	3.4	3.4	3.4	0.0	3.4	3.4	3.4	3.4	3.4	3.4	3.4
jacobian: Summer old sd R (F)	0.0	0.0	0.0	0.0	0.0	0.0	-12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
jacobian: Summer young sd R (F)	0.0	0.0	0.0	0.0	0.0	0.0	-5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
jacobian: Summer young sd R (M)	0.0	0.0	0.0	0.0	0.0	0.0	-12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
jacobian: Winter old sd R (F)	0.0	0.0	0.0	0.0	0.0	0.0	-12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
jacobian: Winter young sd R (F)	0.0	0.0	0.0	0.0	0.0	0.0	-5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
jacobian: Winter young sd R (M)	0.0	0.0	0.0	0.0	0.0	0.0	-12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	R5.0	R5.1	R5.2	R5.3	R5.4	R5.5	R5.6	R5.8	R6.1	R6.2	R7.1	R7.2	R7.7	R8.0
observation: Summer old (AC)	0.0	0.0	0.0	0.0	0.0	0.0	829.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
observation: Summer young (AC)	0.0	0.0	0.0	0.0	0.0	0.0	334.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
observation: CPUE (old)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
observation: CPUE (young)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer old 1/sd R (F)	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young 1/sd R (F)	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young 1/sd R (M)	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer old mu (F)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer old sd L (F)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer old alpha (M)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer old mu (M)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer old sd L (M)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young mu (F)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young sd L (F)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young alpha (M)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young mu (M)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: Summer young sd L (M)	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prior: CPUE q	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	0.0
Total	1870.9	1860.4	1887.3	1862.3	1929.9	1869.8	2129.2	1871.0	3551.6	1027.5	1871.0	1871.3	2049.7	1870.9