Integrated stock assessment for the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2

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Table of contents

1 Recommendation 1

2 Abstract 1

3 Introduction 2

4 Stock hypothesis 2

5 Data 4
5.1 Catch data . . . 4
5.2 Random stratified trawl surveys (RSTS) . . . 5
5.3 Commercial sub-fisheries . . . 8
5.4 Tagging data . . . 9
5.5 Length and ageing data . . . 12
5.6 Length-at-age estimation . . . 12
5.7 Length-weight relationship . . . 13
5.8 Maturity-at-age . . . 14
5.9 Other biological parameters . . . 15
5.10 Ageing error matrix . . . 15
5.11 Comparison with previous Casal2 assessment . . . 16

6 Methods **18**
6.1 Model configuration . . . 18
6.2 Selectivity and movement functions . . . 19
6.3 Model estimating procedure . . . 20
6.4 Calculations of catch limits . . . 22

7 Results **22**
7.1 MPD estimates . . . 22
7.2 Model fits . . . 23
7.3 Likelihood profiles . . . 31
7.4 Sensitivity analyses . . . 32
7.5 Retrospective analysis . . . 34
7.6 MCMC estimates . . . 35
7.7 Calculations of catch limits . . . 39
7.7.1 Sensitivity of recruitment assumptions to catch limits . . . 40
7.7.2 Calculation of the constant harvest rate multiplier and associated catch limit . . . 41

8 Discussion **42**

Acknowledgements **45**

References **45**

Appendix **51**
Reference model diagnostics . . . 51
MCMC diagnostics . . . 62
Results and model fits for sensitivity (e) - recruitment deviations estimated to 2019 . . . 65
Results and model fits for sensitivity (f) - including 9 years at liberty for tag data . . . 68
General summary of responses to climate change indices . . . 71

1 Recommendation

1. That WG-FSA support the spatially-explicit, sex disaggregated, integrated stock assessment model implemented in TMB to assess stock structure and make management decisions for Patagonian toothfish (*Dissostichus eleginoides*) in Division 58.5.2.
2. Based on the 2026 reference case and using the CCAMLR Decision Rule we recommend a proposed two-year catch limit of 3,503 tonnes for Patagonian toothfish (*Dissostichus eleginoides*) in Division 58.5.2 in CM 41-08.

2 Abstract

This paper presents an updated stock assessment for Patagonian toothfish (*Dissostichus eleginoides*) in the Heard Island and McDonald Islands (HIMI) in CCAMLR Division 58.5.2. The 2026 assessment is a integrated spatial, sex- and age-structured population dynamics model that fits to the Random Stratified Trawl Survey (RSTS) abundance index, tag-recapture data using a Brownie likelihood, along with length frequency and conditional-age-at-length data. The assessment was implemented in TMB and differs from the previous assessment conducted using a non-spatial and sex-aggregated approach and was implemented in Casal2. Additional changes to the stock assessment include calculation and estimation using length-based processes rather than age-based (i.e., selectivity, maturity and growth). The 2026 assessment includes: (i) updated catch data to 2026 and observations to the end of 2025, including new ageing data from the RSTS and commercial fishery, and (ii) re-estimated growth, maturity and tag-shedding parameters. Inspection of diagnostics and models fits suggest that there has been a significant improvement in model specification and processes, compared to previous assessments. The assessment leads to MCMC-derived estimates of virgin spawning stock biomass, SSB_0, of 77,859 (95% CI: 75,738–80,280 tonnes) and a SSB status at the end of 2025 of 0.424 (95% CI: 0.411–0.436). Based on the result of this assessment and the CCAMLR decision rules, a catch limit of 3,503 tonnes was calculated.

This revision includes revised length sample numbers and a model run with revised SIOFA catches, included as sensitivity (k). The length sample numbers were correct in the assessment, where the number of hauls are included as the initial sample size, whereas the number of total number of length measurements taken are presented in this paper, the updated numbers are presented in Table 3. This sensitivity run (k) estimated the same stock status estimate as the reference model presented here with a slightly higher estimate of SSB_0, shown in Table 9 and resulting catch limit, shown in Table 11.

3 Introduction

A number of stock assessments have been developed in recent years for the fishery for Patagonian toothfish (*Dissostichus eleginoides*) at Heard Island and McDonald Islands (HIMI) in CCAMLR Division 58.5.2 (Candy and Constable 2008; Candy and Welsford 2009, 2011; Ziegler et al. 2013, 2014; Ziegler and Welsford 2015; Ziegler 2017a, 2019; Ziegler 2021; Masere and Ziegler 2023, 2024). These assessments have been implemented in CASAL and Casal2 (Bull et al. 2012; Casal2 Development Team 2023) and were conducted under a sex-aggregated approach assuming a single, well-mixed population.

This year's stock assessment incorporates a fundamentally different structure, as it is now spatially and sex-structured. This assessment also fits to conditional age-at-length and length frequency data rather than age frequency data and a number of processes are now length-based, rather than age-based (Leadbetter et al. 2026a). The motivation for these changes was

outlined in Masere et al. (2025). The first iteration of the new approach for the HIMI stock assessment, including methodology and structure, was presented to WG-SAM-2026 (Hillary et al. 2026). This paper collates progress and summarises ongoing work, while also providing a wide suite of diagnostics to discern the relative fit and robustness of the 2026 stock assessment for Patagonian toothfish at HIMI.

4 Stock hypothesis

The Kerguelen Plateau is located in the Southern Indian Ocean and stretches from around 45°S to over 60°S. Almost all of the Kerguelen Plateau is situated within the area managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), with only a small extension, the William's Ridge, on the eastern side of the northern part of the Plateau extending into the Southern Indian Ocean Fisheries Agreement (SIOFA) Statistical Area 7.

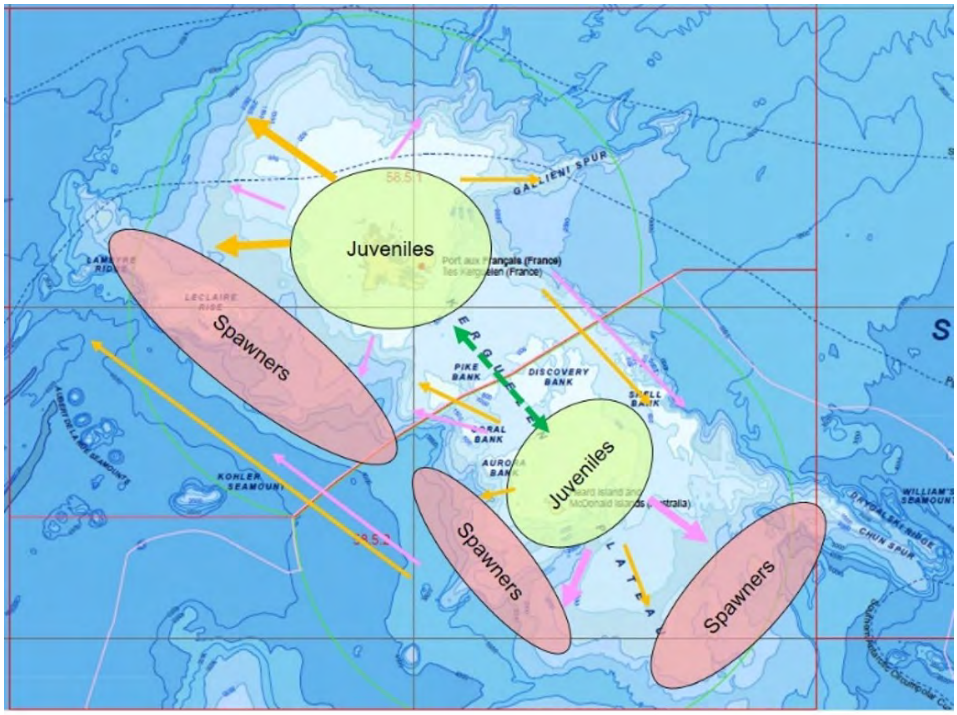


Figure 1: Schematic toothfish population structure on the northern part of the Kerguelen Plateau with Kerguelen Island to the north and Heard Island and McDonald Islands to the south. Juveniles settle in shallow waters on the plateau around the islands with potential exchange between areas (dark green arrows). Males (orange arrows) and females (pink arrows) then move into deeper waters as they grow larger and older, with major spawning grounds on the western and southern side of the plateau. CCAMLR Divisions are marked by red lines.

On the northern part of the plateau (north of Fawn Trough, or roughly 57°S), two large fisheries for Patagonian toothfish are located, including CCAMLR Division 58.5.1, which covers the French Exclusive Economic Zones (EEZ) around Kerguelen Islands, and Division 58.5.2, which covers the Australian EEZ around HIMI. On the southern part of the Kerguelen Plateau, Antarctic toothfish (*D. mawsoni*), which is better adapted to the colder waters around the Antarctic continent, is the dominant toothfish species.

Based on available genetic information (Toomey et al. 2016), catch composition (Péron et al. 2016) and tag-recapture data from survey and the commercial toothfish fishery (Burch et al. 2017; Ziegler et al. 2021), Patagonian toothfish are continuously distributed on the northern part of the Kerguelen Plateau and populations are linked. Within this area, juveniles settle in the shallow waters around the islands and there is potential exchange between Kerguelen Islands and HIMI (Figure 1). As fish grow larger and older, they move to deeper waters, and major spawning grounds are located on the western and southern side of the plateau.

5 Data

5.1 Catch data

Data from random stratified trawl surveys (RSTS) and the commercial fishery in Division 58.5.2 were available for the period from 1997–2025 (Table 1). The haul-by-haul data from the RSTS, longline, trawl and trap included information on *inter alia* fishing date, haul latitude and longitude, fishing depth, gear type, effort, and total catch in weight and numbers. Relevant biological data collected by observers included the total length and weight of all sampled fish. Biological data were excluded if the quality of the record had been flagged as being poor. Observers also collected fish otoliths that were used for ageing fish. For the assessment, catches were summarised by RSTS and commercial sub-fisheries, and fishing season.

Fishing-induced mortality from lost longline gear was estimated from the numbers of hooks that were lost. Gear loss was included when more than 100 hooks were lost at a time since incidental loss of small numbers of hooks and snoods may occur on longline operations without loss of any line, particularly at the transition between magazines. The numbers of lost hooks were then multiplied with the mean of catch per hook for that year as recommended by WG-SAM-19 (para. 3.5) (Table 1, Figure 2).

Illegal, unreported and unregulated (IUU) catches in CCAMLR Division 58.5.2 were potentially large in the late 1990s and early 2000s. IUU catches were estimated based on sightings of IUU vessels, their known fishing capacities, and catch and effort data from the licensed fishery (Table 1). No IUU vessel has been sighted after 2005 and it is likely that no IUU catches have been taken since then.

Fishery operations by Australian fishing vessels at HIMI were initially undertaken using trawl gear and restricted to relatively shallower (less than 1,000 m) waters. In 2003 longlining began in shallower fishing grounds in the eastern part of the Division and has expanded substantially to deeper fishing grounds and up to the northwest corner over the years. Since 2014 almost the entire catch has been taken by longline vessels. There was a maximum of 3 vessels operating between 1997 to 2012 - as well as in 2023–2026. Four vessels were active in 2013-2014, 2016-2018 and 2022. Between 2019–2021 there were 5 vessels operating in HIMI. Finally, there has been just one season in which 7 vessels were active (i.e., 2015).

In 2018, the Spanish vessel FV Tronio, and in 2019 a second Spanish vessel, the FV Ibsa Quinto, fished for Patagonian toothfish on William's Ridge in SIOFA area 7. Fishing was subsequently regulated for the 2019/20 season onwards in CMM 2019/15. Total annual catches on William's Ridge have been limited to 140 tonnes, and there are also effort limitations in place, with no more than two longline sets with a maximum of 6,250 hooks per line to be set in each 15'x15' grid cell.

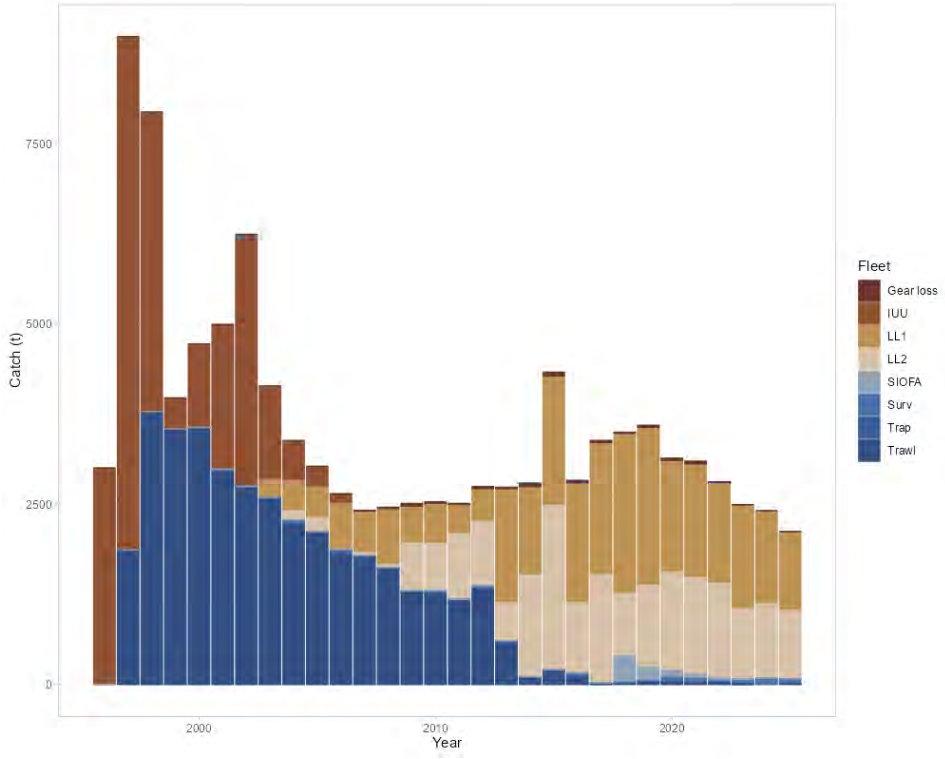


Figure 2: Summary of catch and loss from within the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2 from 1996 to present. Longline catches were split into shallow (LL1) and deep (LL2) fisheries.

5.2 Random stratified trawl surveys (RSTS)

The RSTS have been conducted in Division 58.5.2 to estimate the abundance and size structure of *D. eleginoides* and mackerel icefish (*Champsocephalus gunnari*) in 1990, 1992, 1993, and annually since 1997. However, the structure and intensity of the surveys has varied over these years as the objective for the surveys has changed, and information for survey design and power has improved (Welsford et al. 2006).

For example, the initial three surveys in the early 1990s were conducted to gain a basic understanding of the distribution and abundance of fish stocks in the region, occurred at different seasons, and used a relatively small number of trawls. The surveys in 1997–1998 targeted icefish and are not suitable to estimate toothfish abundance. Major surveys incorporating a wider range of toothfish habitats started in 1999, although for the first four years different stratum plans based on specific research questions for toothfish and icefish resulted in varying effort to survey toothfish. The large shallow strata sampled in the 1999 survey were subdivided in 2001 and the deeper strata in 2002, after which the strata boundaries have been stable. In

2000, only a relatively small area was surveyed, and the northern plateaus were not sampled in 2003. After reviewing the statistical power of the surveys in 2003, trawl allocation to strata with greater fish abundance was increased (Candy et al. 2004).

Table 1: CCAMLR catch limits, reported catch for the random stratified trawl survey (RSTS), trawl (T), longline (LL) and trap, estimated fishing-induced mortality from lost longline gear, reported or estimated catches in the SIOFA area, revised SIOFA catches, estimated IUU catch, and total removals in tonnes by calendar year for Division 58.5.2.

Year[a]	Catch limits	RSTS	T	LL	Trap	Reported catch total	Gear loss	SIOFA catch[c]	Revised SIOFA catch[d]	Estimated IUU catch	Total removals
1996	297	0	0	0	0	0	0	0	0	3000	3000
1997	3800	0	1866	0	0	1866	0	0	0	7117	8983
1998	3700	1	3784	0	0	3785	0	0	0	4150	7935
1999	3690	93	3452	0	0	3545	0	0	0	427	3972
2000	3585	9	3556	0	0	3565	0	0	0	1154	4719
2001	2995	45	2942	0	0	2987	0	0	0	2004	4991
2002	2815	35	2717	0	0	2752	0	0	0	3489	6241
2003	2879	13	2580	270	0	2863	0	0	0	1274	4137
2004	2873	65	2218	566	0	2849	0	0	0	531	3380
2005	2787	21	2101	636	0	2758	0	0	0	265	3023
2006	2584	12	1785	659	72	2528	2	0	0	112	2641
2007	2427	12	1775	625	0	2412	4	0	0	0	2415
2008	2500	4	1614	825	0	2443	13	0	0	0	2455
2009	2500	20	1268	1173	13	2474	36	0	0	0	2502
2010	2550	28	1239	1216	32	2515	17	0	0	0	2529
2011	2550	6	1142	1317	33	2498	12	0	0	0	2508
2012	2730	41	1322	1356	0	2719	25	0	0	0	2735
2013	2730	8	555	2116	40	2719	15	0	0	0	2731
2014	2730	13	93	2638	0	2744	40	0	0	0	2780
2015	4410	26	180	4073	0	4279	50	0	0	0	4322
2016	3405	52	107	2640	0	2799	30	0	0	0	2825
2017	3405	20	3	3334	0	3357	27	0	0	0	3380
2018	3525	41	8	3091	0	3140	12	347	339	0	3499
2019	3525	29	38	3333	0	3400	25	169	127	0	3594
2020	3030	84	34	2919	0	3037	30	71	74	0	3135
2021	3030	78	15	2921	4	3018	35	43	38	0	3096
2022	3010	36	30	2709	0	2775	5	29	32	0	2809
2023	3010	67	3	2424	0	2494	0	0	25	0	2494
2024	2660	86	0	2322	0	2408	0	0	28	0	2408

Table 1: CCAMLR catch limits, reported catch for the random stratified trawl survey (RSTS), trawl (T), longline (LL) and trap, estimated fishing-induced mortality from lost longline gear, reported or estimated catches in the SIOFA area, revised SIOFA catches, estimated IUU catch, and total removals in tonnes by calendar year for Division 58.5.2.

Year[a]	Catch limits	RSTS	T	LL	Trap	Reported catch total	Gear loss	SIOFA catch[c]	Revised SIOFA catch[d]	Estimated IUU catch	Total removals
2025	2120	68	9	2040	0	2117	0	0	0	0	2117
2026	2120	20	0	2100	0	2120	0	0	0	0	2120[b]

[a] Fishing seasons run from 1 December - 30 November of the following year. Here, years are denoted after the year with the majority of the season, e.g. 1996/97 is 1997.

[b] For the assessment, it was assumed that 2,120 t were taken, with a survey catch of 20 tonnes.

[c] SIOFA data, and from the SIOFA website (Management of Demersal Stocks | SIOFA (apsoi.org)).

[d] Revised SIOFA catches from SIOFA Secretariat (2026), used in sensitivity run (k).

Since 2003, an annual survey has consisted of between 120–160 trawl hauls, each taking approximately 30 mins tow time on the seabed to complete. The entire fishable area in Division 58.5.2 down to 1,000 m is divided into ten strata (of which one is excluded from sampling since it is closed to fishing), each covering areas of similar depth and/or fish abundance (Nowara et al. 2017). A list of random co-ordinates for starting position and prescribed headings for each station in each stratum is provided to the fishing vessel conducting the survey, including first choice and reserve positions. In the surveys until 2014, the sampling area of the main trawl fishing ground, which is around 450 km^2, was subdivided into squares of 2 x 2.4 nautical miles (0.5 x 0.5 degrees). Sampling occurred in a randomly selected subset of 20 out of the total of 30 of these squares, with details provided in the survey instructions. Since the 2015 survey, the main trawling ground has been subdivided into two sub-strata, and as in the other strata vessels have been provided with random co-ordinates for starting positions and headings. The number of stations in the main trawl ground has also been increased to 25.

Survey observations were separated into a survey biomass index and survey composition data. The annual survey biomass and *CVs* for 2001–2002 and 2004–2025 ('Survey group 1' in Ziegler et al. (2014); Ziegler and Welsford (2015); Ziegler (2017a)) were estimated as the sum of biomass estimates in each surveyed stratum which were derived from a stratified bootstrap of the estimated fish density in survey hauls. In some instances, very large survey hauls were omitted as they introduced a significant amount of variability into the estimates and were identified as outliers. This practice was useful for improving the statistical behaviour

of this index, however, it also introduced a small negative bias into the survey time series. In the assessments up to 2013, this survey group had been assumed to fully sample the fish stock vulnerable to the fishing gear as quantified by the fishing selectivity function, with survey catchability q set to 1. For the 2014 assessment, catchability for this survey group had been estimated using a prior that was derived from comparing abundance estimates of the survey with abundance estimates calculated from the tag-recaptures data on the main trawl ground (Ziegler et al. 2014). De la Mare et al. (2015) further investigated the ability to estimate survey q from survey and tag-based abundance estimates, but concluded from simulations that a potential bias in the estimate of survey catchability could arise from the need to concurrently estimate fishing selectivity and that this potential bias could not be corrected given the available data. Similar to the assessments in 2015 and 2017, a uniform-log prior for survey q was therefore used in this assessment to account for the multiplicative space within which catchability is applied (Punt and Hilborn 2001). Annual RSTS biomass estimates for Patagonian toothfish derived from the RSTS are presented annually to WG-FSA (Maschette et al. 2026).

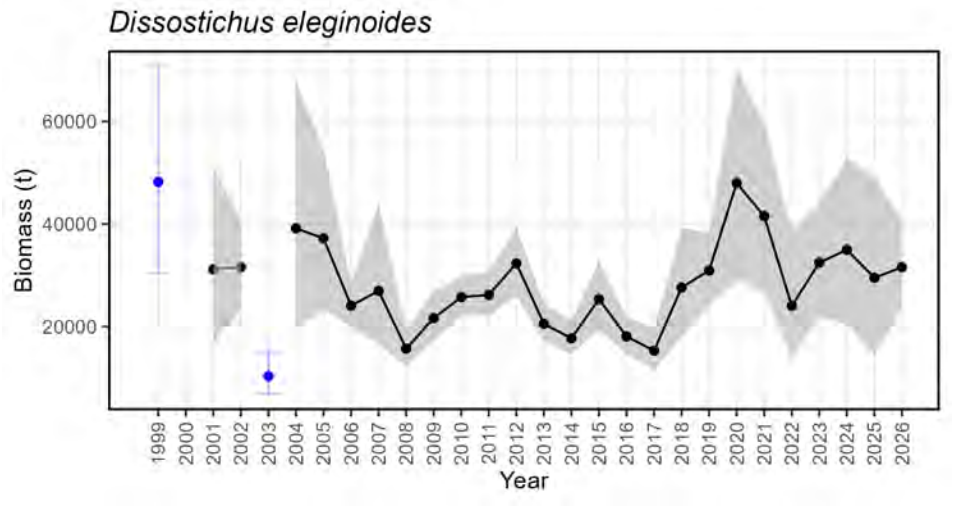


Figure 3: RSTS biomass estimates (tonnes, mean and 95% CIs) for Patagonian toothfish. Biomass estimates from 2001 onwards with consistent survey design are used within the stock assessment. Surveys in 1999 and 2003 (blue) had a different design and were not used.

5.3 Commercial sub-fisheries

Data from commercial hauls were pooled into 'sub-fisheries' based on systematic trends in the catch-at-length distributions of fish in hauls following the method developed by Candy et al. (2013). The definition of sub-fisheries is typically based on gear-specific selectivity and fish

availability in different locations, and sub-fisheries have individual selectivity functions to fit to the available data.

The method by Candy et al. (2013) takes account of the shape of the entire catch-at-length distribution of single or grouped hauls and fits a Generalised Additive Mixed Model (GAMM) with cubic smoothing splines for a combination of covariates (e.g. gear type, depth strata and region). The analysis showed that a split between all gear types and some further splits for longline hauls were appropriate for the toothfish fishery in Division 58.5.2. A depth split at 1,500 m was used for the longline fishery.

Based on this analysis, the commercial sub-fishery structure for the assessment consisted of one trawl (Trawl), one trap (Trap), one shallow longline (LL1) and one deep longline sub-fishery (LL2). IUU catches from Table 1 were included in the assessment and assumed to have been taken by longline, with a selectivity function similar to that of the longline sub-fishery LL1. Similarly, the SIOFA catches were assumed to have been taken with a selectivity function similar to LL1.

5.4 Tagging data

Tagging of *D. eleginoides* in Division 58.5.2 commenced in 1998 soon after the fishery had started. Initially, all tag-releases and recaptures were from trawl. However, trawl effort has been highly concentrated on a small fishing ground, and Candy and Constable (2008) investigated the inclusion of trawl tag-release and recapture data in the stock assessment. They concluded that these tag-recapture data were likely to only estimate the local biomass in the relatively small fishing area where trawl effort had been concentrated, rather than that of the population biomass in the entire Division 58.5.2.

Longlining started in 2003 on shallower fishing grounds in the eastern part of the Division and has expanded substantially to deeper fishing grounds and up to the northwest corner over the years. Within this trend, the spatial effort distribution has varied substantially between years, with an increase in the spatial extent of fishing effort visible in annual fishing activity (Figure 5, WG-FSA-15/55).

Annual tag-release and recapture numbers from longline have increased since 2008, and particularly since 2015 due to a higher catch limit and an increase in tagging rates from 2 fish per 3 tonnes to 2 fish per tonne (Table 2). In total, over 65,000 fish have been tagged and released and over 11,000 have been recaptured since 2012. The maximum depth of fishing during this time has remained relatively stable, however, there are some years where there was notable effort in shallower waters as well as deeper waters.

While tagged toothfish are unlikely to mix completely within the fished part of the population (Williams et al. 2003; Welsford et al. 2007, 2014), only longline-caught fish that have been tagged and released from 2012 onwards have been used in assessment, as was the case in previous assessments (Ziegler 2017a, 2019; Ziegler 2021; Masere and Ziegler 2024) since longline

effort had been spatially more spread out from that year onwards. For the 2013 to 2024 longline fisheries' release years that are used in the assessment 58,837 fish have been released and 11,506 have been recaptured within the maximum 6 year post-release recapture window.

Table 2: Numbers of longline tag-releases and tag-recaptures reported since 2012. Within-season recaptures are not used in the assessment. Recaptures that were caught between one to six years at liberty were considered in tagging analyses.

Release year	n	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
2013	1423	53	98	43	52	47	13	-	-	-	-	-	-	306
2014	1749	-	79	72	85	48	45	31	-	-	-	-	-	360
2015	7599	-	-	283	359	299	275	185	121	-	-	-	-	1522
2016	5235	-	-	-	221	296	266	160	138	85	-	-	-	1166
2017	6630	-	-	-	-	343	422	353	285	191	113	-	-	1707
2018	5486	-	-	-	-	-	441	228	386	190	116	80	-	1441
2019	6176	-	-	-	-	-	-	239	453	340	255	140	86	1513
2020	4317	-	-	-	-	-	-	-	242	258	204	132	73	909
2021	5757	-	-	-	-	-	-	-	-	427	289	275	189	1180
2022	5089	-	-	-	-	-	-	-	-	-	271	285	186	742
2023	4773	-	-	-	-	-	-	-	-	-	-	230	192	422
2024	4603	-	-	-	-	-	-	-	-	-	-	-	238	238

In the assessment, the numbers of longline tag-releases and tag-recaptures used were historically capped at 6 years at liberty to account for tag-shedding rates in CASAL being specified for fish tagged with a single tag, while all released fish are double tagged (Candy 2011b; Dunn et al. 2011), and within-season recaptures were excluded (Table 2). Tag-release mortality was assumed to be 0.1 (Agnew et al. 2006), and a no-growth period after tagging of 0.5 years was assumed (Agnew et al. 2005).

Table 3: Number of toothfish measured for length or age and used in the assessment for the RSTS and commercial fisheries.

Year	Length (Plateau)	Length (Shelf)	Length (Total)	Age (Plateau)	Age (Shelf)	Age (Total)
1997	9229	0	9229	140	0	140
1998	11408	0	11408	181	0	181
1999	14650	0	14650	78	0	78
2000	20525	0	20525	783	0	783
2001	30108	0	30108	794	0	794
2002	21489	0	21489	824	0	824

Table 3: Number of toothfish measured for length or age and used in the assessment for the RSTS and commercial fisheries.

Year	Length (Plateau)	Length (Shelf)	Length (Total)	Age (Plateau)	Age (Shelf)	Age (Total)
2003	23305	4194	27499	472	170	642
2004	21809	14422	36231	338	2	340
2005	19412	13138	32550	741	411	1152
2006	17315	16220	33535	637	573	1210
2007	16151	8785	24936	764	364	1128
2008	16331	16600	32931	759	185	944
2009	15151	31281	46432	721	175	896
2010	20268	18466	38734	1057	167	1224
2011	13211	24941	38152	589	240	829
2012	23159	20065	43224	717	166	883
2013	9751	35897	45648	402	1097	1499
2014	2770	42791	45561	570	1129	1699
2015	6074	71534	77608	657	538	1195
2016	5630	51441	57071	316	566	882
2017	2592	64789	67381	304	541	845
2018	3787	58553	62340	323	631	954
2019	3904	61196	65100	278	562	840
2020	4738	25316	30054	300	444	744
2021	4455	39662	44117	160	671	831
2022	3239	47205	50444	326	1338	1664
2023	3636	36036	39672	320	363	683
2024	2684	36627	39311	305	532	837
2025	4124	28267	32391	306	529	835

The tag-detection rate during longline fishing was assumed to be 100%, and tag-shedding rates were estimated following the method proposed by Adam and Kirkwood (2001) as detailed in Bessell-Browne et al. (2026). The model used was a two-parameter model that assumes an initial one-off instantaneous loss of a tag post-release, and an exponential rate of tag loss after this point. For the two parameter model the maximum likelihood parameter estimates (and their approximate standard errors) were $\psi = 0.9741$ (0.0018), and $v = 0.0434$ (0.0011). Even for the 10 years at-liberty, used as a maximum timeframe here (almost double what has been used as a cut off in previous assessments), the probability of retaining at least one tag, given double-tagging at release, is around 86%.

5.5 Length and ageing data

A large number of toothfish have been measured annually for length and more than 1.25 million otoliths have been aged (Table 3). All ages have been estimated by technicians that have been trained following the recommendation of the 2012 toothfish ageing workshop (SC-CAMLR 2012) and the protocols for thin sectioning developed at the Australian Antarctic Division (AAD) (Welsford et al. 2012; Farmer et al. 2014; Ziegler et al. 2021).

5.6 Length-at-age estimation

Similar to previous assessments, length-at-age data was re-estimated using all randomly sampled and aged fish from 1997–2025. Fish records with a poor quality flag, missing data, doubtful length measurements, or poor age reads (e.g. a poor readability score) were excluded. For otoliths with multiple reads, the median age was taken (rounded to the next integer age where applicable).

There is ageing data available from 1993 up to and including 2025 for the HIMI Patagonian toothfish stock, with this data including 15,642 female and 10,454 male length-age measurements. Given the additional data available since the previous growth update for this stock and a move to sex-specific growth within the stock assessment, an update of this relationship is required (Masere and Ziegler 2024). The approach used to estimate growth follows that previously applied for the Macquarie Island Patagonian toothfish stock assessment, which implements a Schnute parameterisation of the von Bertalanffy growth function that accounts for selectivity impacts and ageing error (Bessell-Browne and Hillary 2025).

While previous growth estimates have been combined across sexes (Masere and Ziegler 2023), we have calculated sex-specific estimates here, which makes comparisons challenging. However, the L_∞ estimate for females was higher than the previous estimate, while the male estimate was lower (Figure 4). The growth parameters are very accurately estimated for both sexes with females generally being longer-at-age than males from age 5 onwards. Variability in length-at-age is estimated to be essentially the same for both sexes. Fits to the mean age-at-length data are good, and the multinomial distribution appears appropriate for the age-given-length data. Fits to the female length frequencies is not as good as for males, and this appears to be driven by the grouping of samples across fleets with differing selectivities (survey compared to longline). Further details of the method and results are provided in Bessell-Browne et al. (2026).

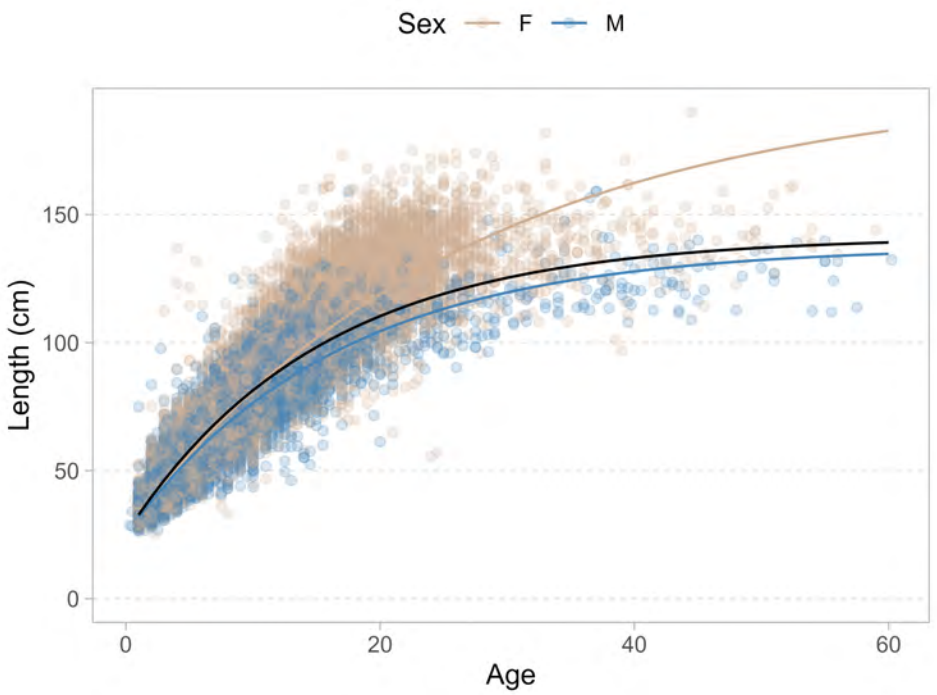


Figure 4: Estimated growth curve for females and males (lines) with data used to estimate parameters (points). The black line shows the sex aggregated relationship used in the 2024 assessment. Age is measured in years.

Table 4: Maximum likelihood estimates (and approximate standard errors in brackets) of key estimated parameters and process variables for each sex. The sex-aggregated 2023 estimates are included for comparison.

Variable	k	l_1	l_2	l_{inft}	t_0	$sigma_l$	phi_l
Female	0.038	56.42	118.92	200.69	-3.72	0.145	14.54
	(0.002)	(0.22)	(0.43)	(5.93)	(0.16)	(0.014)	(1.17)
Male	0.061	54.72	104.44	137.51	-3.29	0.143	8.70
	(0.003)	(0.20)	(0.63)	(2.98)	(0.16)	(0.012)	(1.02)
2023 estimates	0.066			141.3	-3	0.138*	

5.7 Length-weight relationship

The same length-weight relationship as estimated for the 2019 stock assessment (Ziegler 2019) was used in this assessment (Figure 5).

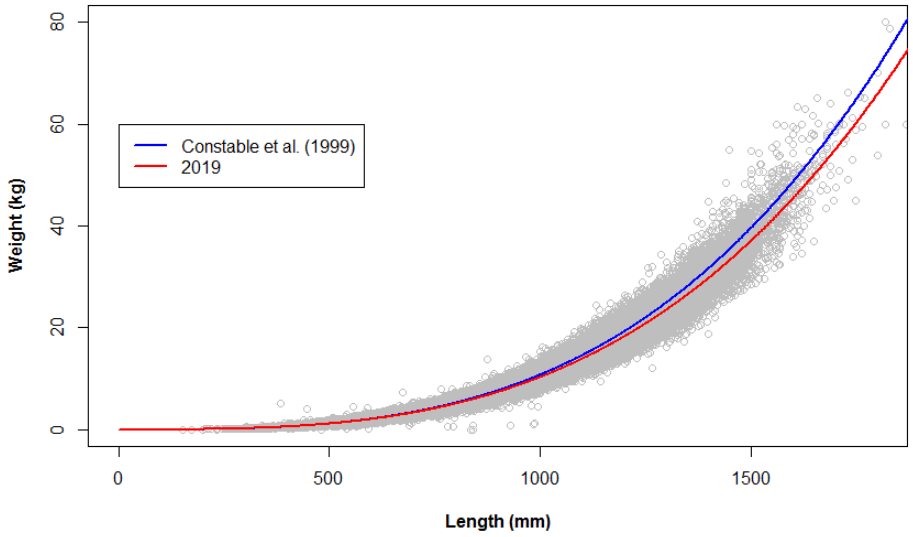


Figure 5: Estimated Weight-at-length relationships.

5.8 Maturity-at-age

For this stock assessment maturity-at-length is the key relationship, translated through the distribution of length-at-age to get an expected maturity-at-age relationship, which is used to define the female spawning population abundance and age structure. The method used to estimate these key parameters was based on the approach developed and used for the Macquarie Island Patagonian toothfish stock assessment (Kock and Kellermann 1991). This approach differs to that used in previous HIMI Patagonian toothfish assessments, where maturity-at-age was the key input relationship (Masere and Ziegler 2024). This analysis is detailed in Bessell-Browne et al. (2026).

For females there were 550,996 measurements with both maturity state and length, for males there were 385,119. For females $\mu = 100.09$ and $\nu = 6.66$; for males $\mu = 78.99$ and $\nu = 6.50$, where μ is length at 50% maturity and ν in the difference in length between 50% and 95% maturity. In both cases, given the quality of the fits to the data (see Bessell-Browne et al. (2026) for details of fits), and the number of data points, the CVs are around 1% or less. The maturity-at-length relationship for both females and males is shown in Figure 6.

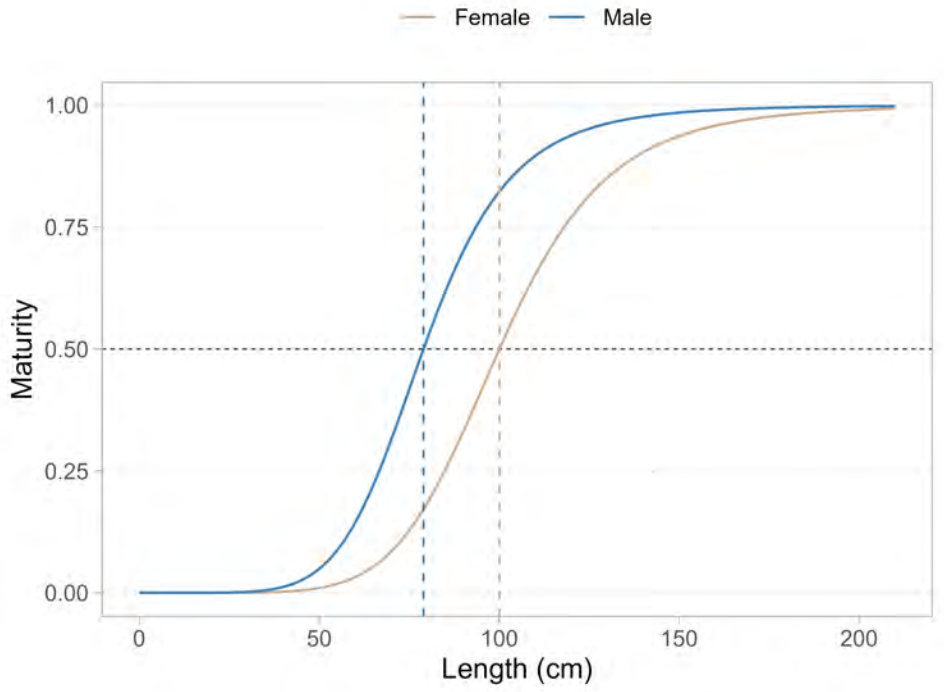


Figure 6: Estimated maturity-at-length relationships for both males and females.

5.9 Other biological parameters

Other biological parameters are specified in Table 5. Natural mortality was estimated to be 0.155 (Candy 2011a; Candy et al. 2011) and was input to the assessment as a pre-specified parameter that was assumed to be constant across all age classes and time, and the stock recruitment relationship was assumed to follow a Beverton-Holt function with steepness $h = 0.75$ (Dunn et al. 2006).

5.10 Ageing error matrix

In 2014, the method of Candy et al. (2012) to estimate the ageing error matrix was revised by Burch et al. (2014) to address some issues regarding true ages not being the mode at the extremes of the matrix and a lack of smoothness in the probabilities for ages above 25 years. At the same time, the reference collection was expanded to include an additional 50 otoliths, read by four or more readers, that had a mean fish age of 25 years or greater. For this assessment, the same ageing error matrix was used.

5.11 Comparison with previous Casal2 assessment

A bridging analysis from the 2024 Casal2 stock assessment to a single-area, sex disaggregated TMB-based assessment was presented to WG-SAM-2026 (Leadbetter et al. 2026b). The bridging analysis began with the 2024 Casal2 stock assessment presented to WG-FSA-2024 (Masere and Ziegler 2024) and sequentially incorporates: (1) sex disaggregation and alternative approaches for developing age frequencies; (2) data up to 2026 and updated biological parameter estimates; and (3) length selectivity. The analysis then compares the resulting 2026 single-area, sex-disaggregated assessment conducted in Casal2 against a equivalent population dynamics structure, implemented in TMB (i.e., non-spatial, sex-disaggregated). There were still some differences in the assessment applied, including that the model implemented in TMB was fit to conditional age-at-length and length-frequency data, incorporation of length-based maturity, and use of a Brownie likelihood for the tag-recapture data. Table 5 highlights the similarities and differences in assessment structure between the final Casal2 assessment from Leadbetter et al. (2026b) and the two area TMB assessment.

Table 5: Population parameters and their values for the previous Casal2 based assessment and the current TMB based assessment. Sex-specific values are shown in brackets (females, males).

Parameters	2024 Casal2 assessment	2026 TMB assessment
Assessment period	1982-2024	1987-2026
σ_R for projections	Calculated from YCS	Calculated from YCS
	1986-2018	1988-2017
Population structure	Sex-aggregated	Sex-disaggregated
	Single-area	Two-area
Size-at-age	Masere and Ziegler (2024)	Bessell-Browne et al. (2026)
L_∞	1412.94	(2006.9, 1375.1)
k	0.0658	(0.038, 0.061)
t_0	-3.002	(-3.72, -3.29)
CV	0.138	(0.146, 0.144)
Ageing error matrix	Burch et al. (2014)	Burch et al. (2014)
Weight-at-length	Masere and Ziegler (2024)	Masere and Ziegler (2024)
c	3.61E-12	3.61E-12
d	3.1518	3.1518
Maturity	Masere and Ziegler (2024)	Bessell-Browne et al. (2026)
a_{50}	13.7 years	(100cm, 79cm)
Natural mortality (M)	Candy (2011a)	Candy (2011a)
	0.155	0.155

Parameters	2024 Casal2 assessment	2026 TMB assessment
Survey catchability (q)	Estimated	Estimated
Tagging:		
Tag detection	Ziegler (2017a)	Ziegler (2017a)
	1	1
Tag-release mortality	Agnew et al. (2006)	Agnew et al. (2006)
	0.1	0.1
No-growth period	Agnew et al. (2005)	Agnew et al. (2005)
	0.5 years	0.5 years
Tag shedding	Ziegler (2017b)	Bessell-Browne et al. (2026)
rate	0.056	0.043
instantaneous	0.028	0.026
Emigration	Burch et al. (2017)	Burch et al. (2017)
	0.01	0.01
Years at liberty	6	6
Selectivity:		
Survey	Double-normal	Constant
Trawl	Double-normal	Logistic (time-varying)
LL1	Double-normal	Double normal
LL2	Double-normal	Double normal
Trap	Double-normal plateau	Logistic
IUU	Same as LL1	Same as LL1
SIOFA	Same as LL1	Same as LL1
Gear loss	Same as LL1	Same as LL1

Table 6: Data used for the previous Casal2 based assessment and the current TMB based assessment.

Data	2024 Casal2 assessment	2026 TMB assessment
Catch:		
Survey	2001-2024	2001-2025
Trawl	1997-2024	1997-2025
LL1	2003-2024	2003-2025
LL2	2004-2024	2004-2025
Trap	2006-2023	2006-2025
IUU	1996-2023	1996-2025
SIOFA	2018-2023	2018-2025
Gear loss	2003-2023	2003-2025

Data	2024 Casal2 assessment	2026 TMB assessment
RSTS:		
Biomass index	2001-2022	2001-2025
Composition	2006-2022	2006-2025
age-length	-	2001-2025
Commercial:		
Composition	1998-2022	1998-2025
Tag-releases	2012-2021	2012-2025
Tag-recaptures	2013-2022	2013-2025
age-length	-	1997-2025

6 Methods

6.1 Model configuration

This is the first implementation of a two-area integrated stock assessment for the stock of Patagonian toothfish at Heard and McDonald Island (HIMI) in Division 58.5.2. The model generalises the sex/season/age-structured model detailed in Leadbetter et al. (2026a), with bridging from the 2024 assessment detailed in Leadbetter et al. (2026b). The model itself is written in TMB, an R-based $C++$ library that permits the automatic calculation of derivatives. This can be linked to optimisation and Markov chain Monte Carlo (MCMC) software in R to permit maximum likelihood estimation for non-linear mixed effect models, as well as fully Bayesian MCMC approaches.

The assessment was run for the period from 1987–2025. The annual cycle within is divided into four time steps during which (1) fish recruitment, natural mortality and the RSTS is undertaken, (2) commercial fishing takes place (with natural mortality), tagging releases and recaptures, and age-length data collected, and spawning occurring, (3) tag loss and natural mortality, and (4) ageing occurred (Table 7). Recognition of the difference in length (specifically, months) of time steps is accounted for in the model.

The spatial structure of the assessment is as follows:

- **Plateau**: this region is where recruitment occurs exclusively, and where the random stratified trawl survey (RSTS) and trawl fisheries are assumed to be located
- **Shelf**: this region is where the trap and longline fishery are assumed to be located and fish (post recruitment) are permitted to move from the plateau to the shelf

Details of the spatial structuring and model details are provided in Hillary et al. (2026).

6.2 Selectivity and movement functions

The key changes in model structure relate to movement and selectivity. On the plateau we had previously assumed that selectivity would be *a priori* dome-shaped, as one would expect given the smaller fish the RSTS and trawl fisheries catch relative to the trap and longline fisheries. Standard selectivity functions like strictly increasing (logistic) or unimodal (double normal) functions are designed around non-spatial cases where both contact selectivity and availability (due to growth and mortality) are influencing observations.

However, the model initially deposits recruits exclusively onto the plateau and gradually moves them onto the deeper waters of the shelf. Therefore, the main movement information in this model comes from the balance between the following processes:

1. The size distribution in both the RSTS and trawl rapidly decreases at around 70 cm, and the assumption is made that this is an availability effect, not a contact selectivity effect (the fish are not there to be caught but could be if present).
2. By around 50 cm in length, fish start to appear in both the trap and longline fisheries and the only way this can happen, in terms of availability, is if they are beginning to move to the shelf.

Selectivity is generally considered to be a combination of contact selectivity and availability, which is the implicit assumption in a non-spatial model. For the spatial model developed here, selectivity is assumed to be mostly contact selectivity (and not availability) - especially at the smaller lengths that form the majority of the catch from the RSTS and trawl fisheries. This is important because it means that non-standard selectivity functions may be required.

The plateau fisheries have the largest changes in selectivity functions, given fish are actively moving off the plateau as they grow. For the trawl fishery we explicitly assume asymptotic selectivity-at-length (e.g. logistic or smooth knife-edge). We assume that, above a certain estimated length, the trawl could catch any fish on the plateau regardless of their size. An additional feature of the trawl fishery selectivity is a time-dependence for the parameter that defines the length at which fish are fully available. Specifically, this is in the form of a log-scale random walk for the years for that we have length and age-at-length data. For the years prior to these data being available, the selectivity parameter is pre-specified at the initial value; for the years after these data are used this parameter is pre-specified at the final value in the random walk. This was implemented to account for changes in fishing depths that have occurred through time as targeting varied from toothfish to icefish.

The RSTS catches smaller fish than the trawl but has a very similar upper length range of observed fish to the trawl. Given this, we assume that the survey has a contact selectivity of one across all lengths on the plateau. For the shelf-located fisheries we assume an asymptotic form for the trap fishery and dome-shaped selectivity (smooth double normal) for the longline fisheries.

The general model structure of the probability of movement from the plateau to the shelf is a length dependent process. It is modelled on the logit-scale and via a simple linear relationship, $\psi_0 + \psi_1 l$, where l is length and ψ is a logit-scale linear predictor. In general terms, the length dependence in movement can be increasing or decreasing.

For the tag recapture probability random effects, $\epsilon^{rep}_{y,r}$, the random effect SD is itself time-dependent. Specifically, the variance in terms of time-at-liberty τ is defined as follows: $\sigma_\tau = \tilde{\sigma}\exp(-\gamma\tau)$. The variance decay term is defined in terms of a maximum time-at-liberty, τ_{max}, and a total reduction level, δ: $\gamma = \ln\delta/(\tau_{max} - 1)$. For the model we set $\tilde{\sigma} = 0.15$ and $\delta = 0.5$.

Table 7: An overview of the annual cycle of the HIMI Patagonian toothfish assessment model for 2026. Processes included Fishing, Ageing, Recruitment (Rec), Natural mortality (M), Spawning (spawn), Tag release (Tag rel), Tag recpature (Tag rec), the RSTS survey (RSTS) and collection of age and length data (AF/LFs) and their Assigned time step (Time step). Some processes such as natural mortality and tag loss would likely occur consistently throughout the year and so were implemented in each time step. Ageing also occurs throughout the year however is implemented only once per year in an instantaneous (virtual) time step.

Month	Fishing	Ageing	Rec	M	Spawn	Tag rel	Tag rec	RSTS	AFs/LFs	Time step
Dec			x	x						1
Jan				x						1
Feb				x						1
Mar				x				x		1
Apr	x			x		x	x		x	2
May	x			x		x	x		x	2
Jun	x			x		x	x		x	2
Jul	x			x	x	x	x		x	2
Aug	x			x		x	x		x	2
Sep	x			x		x	x		x	2
Oct	x			x		x	x		x	2
Nov		x		x						3, 4

6.3 Model estimating procedure

The assessment models estimated the following parameters:

- Unfished overall recruitment, R_0
- Recruitment deviations ϵ^r_y (1988–2017)
- Selectivity parameters for each fishery (time-varying for trawl)

- Plateau-to-shelf movement parameters (ψ_0, ψ_1)
- RSTS catchability coefficient q
- RSTS process error parameter ($\tilde{\sigma}_{rsts}$)
- Tag recapture random effects, $\epsilon^{rep}_{y,r}$, for each year of release and subsequent recapture event

All models included penalties for recruitment deviations and catch. A penalty for recruitment deviations was intended to force the average of estimated recruitment deviations towards 1. Strong catch penalties prohibited the model from returning an estimated fishable biomass for which the catch in any given year would exceed the maximum exploitation rate set at $U = 0.8$ for each sub-fishery.

Iterative data re-weighting of the length frequency data followed the method TA1.8 described by Francis (2011b) and Francis (2011a) to allow for correlations within the observed length composition data, while the method described by Punt (2019) was used to weight the conditional age-at-length data. Estimates of the RSTS process error parameter, $\tilde{\sigma}_{rsts}$, repeatedly hit the lower bound, suggesting the model did not require additional variability to explain these data; as a result, its value was set at 0.01 and pre-specified thereafter. For the mark-recapture data, the integration step within the Dirichlet-multinomial base likelihood used in the Brownie approach means there is no well defined standardised residual (which is required for Francis weighting). Weighting for this part of the likelihood first involves checking that the predictive distribution encompasses the data at the release year level.

Initially, a point estimate (maximum posterior density, MPD) and its approximate covariance matrix for all free parameters were estimated as the inverse Hessian matrix. Sensitivity analyses on these results were also run to explore stability and robustness of the preferred model to changes in certain parameters including natural mortality, steepness, the time period from which recruitment deviations was estimated, levels of IUU fishing and parameterisation of recruitment deviations. For the final model, these estimates were used as the starting point for Monte Carlo Markov Chain (MCMC) sampling. Additional posterior predictive checks were completed, as well as the sensitivity testing the impact of difference weighting scenarios for this data source on the assessment results using the λ vector (these downweight each data set by the relevant value of λ_i).

MCMC was conducted using the *SparseNUTS* package in *R*, where 1,000 MCMC samples were retained post Markov chain burnin and the convergence of the chains was verified using the *R* package *coda*, as well both effective sample size (N_{eff} - minimum threshold of 400) and $\hat{R}$ (threshold maximum of 1.01) that are default outputs of the MCMC algorithm. Whereas *tmbstan* has been used previously for MCMC, the new package *SparseNUTS* utilises the estimated covariance matrix of the MPD to both de-scale and de-correlate the parameters within the call to the NUTS algorithm in *rstan* and is able to reduce MCMC run times from 2–3 hours to 20–30 minutes.

6.4 Calculations of catch limits

Catch projection trials accounted for uncertainty surrounding parameter estimates of the model as well as future recruitment variability. In order to integrate across uncertainty in the model parameters, MCMC samples were used for TMB's projection procedure to obtain 1,000 random time series samples of estimated numbers of age-1 recruits for the period from 1988–2017, corresponding to recruitment deviation estimates from these years. The median of the square root of the variance of the yearly numbers of these age-1 recruits provided a robust estimate of the σ_R for recruitment required for the lognormal random recruitment generation.

The estimated *CVs* were used to generate the random recruitment from 2017 until the end of the 35-year projection period. Based on this sample of projections for spawning stock biomass, long-term catch limits were calculated following the CCAMLR decision rules:

- Choose a yield, $\gamma 1$, so that the probability of the spawning biomass dropping below 20% of its median pre-exploitation level over a 35-year harvesting period is 10% (depletion probability)
- Choose a yield, $\gamma 2$, so that the median escapement of the spawning biomass at the end of a 35-year period is 50% of the median pre-exploitation level
- Select the lower of $\gamma 1$ and $\gamma 2$ as the yield

The depletion probability was calculated as the proportion of samples from the Bayesian posterior where the predicted future spawning biomass was below 20% of SSB_0 in the respective sample at any time over the 35-year projected period. The level of escapement was calculated as the proportion of samples from the Bayesian posterior where the projected future status of the spawning biomass was below 50% of SSB_0 in the respective sample at the end of the 35-year projection period.

Estimates of the catch limit assumed constant annual catches. Future surveys were assumed to be conducted every year with catch splits based on the average proportion of catch taken by each fishery over the last four years before projections commence.

7 Results

7.1 MPD estimates

The MPD assessment (reference model) produced point estimates for a number of values, including virgin spawning stock biomass (SSB_0 = 77,858), recruitment (R_0 = 4,217,120), and survey catchability (q = 1.83). Contributions of various components to the log likelihood function for this initial MPD run are presented in Table 8.

Table 8: Contributions to the objective function for the MPD assessment run (reference model)

Component	Reference model
tag_release_2013	-3441.22
tag_release_2014	-4268.47
tag_release_2015	-18906.56
tag_release_2016	-12670.67
tag_release_2017	-15402.00
tag_release_2018	-12769.35
tag_release_2019	-14637.67
tag_release_2020	-10761.92
tag_release_2021	-14674.99
tag_release_2022	-14023.86
tag_release_2023	-14151.10
tag_release_2024	-14367.24
Index	17.51
Surv length (unsexed)	2953.51
Surv length (sexed)	10141.25
Trawl length (sexed)	37981.47
Trap length (sexed)	2829.02
LL1 length (sexed)	52259.73
LL2 length (sexed)	36192.46
Surv age-length	3937.28
Trawl age-length	3559.45
Trap age-length	788.53
LL1 age-length	3751.67
LL2 age-length	4288.29
Priors	-8.34
Total	8616.80

7.2 Model fits

Model fit was explored for a variety of assessment outputs. The general trend shown in RSTS biomass were fairly consistent, although both the lowest and highest values proved more difficult to capture (Figure 7).

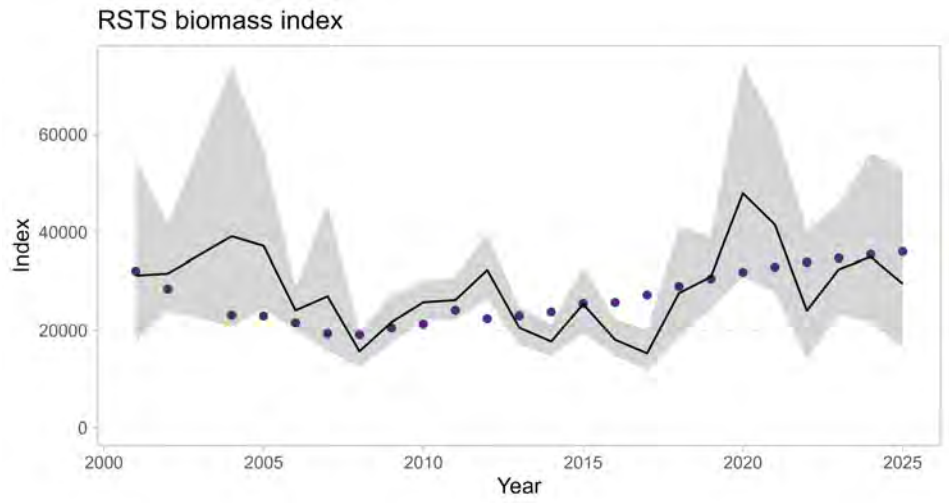


Figure 7: Observed (median and 95th percentile, line and shaded area) and predicted (circles) RSTS biomass index values.

Fits to length for each sex by gear type were also examined. For longline gear in both depth classes, mean length of females was relatively well fit with some overestimation of length evident in 2007 and 2008 as well as in the last three years of the model (2023–2025) (Figure 8). However, the model appeared to consistently overestimate mean length for males for this same gear type (and both depths) (Figure 9). Fits to individual length frequencies demonstrate that while the mode and lower limb are fitting well, there is slight overestimation of the higher lengths (Figure 34, Figure 36).

The fit of mean length of females, males and unsexed fish to the RSTS was generally good with observed values tracking predicted values well with a small degree of variation (Figure 8, Figure 9).

There has been considerably less fishing activity undertaken with trap gear in HIMI. Mean length for females is reasonable (Figure 8), whereas males again appear to be overestimated in length, particularly in early years (Figure 9). Mean length overestimation is evident for both sexes in the trawl fishery also (Figure 8, Figure 9).

Fits to annual length frequency plots by fishery and sex are shown in Figure 26 – Figure 36.

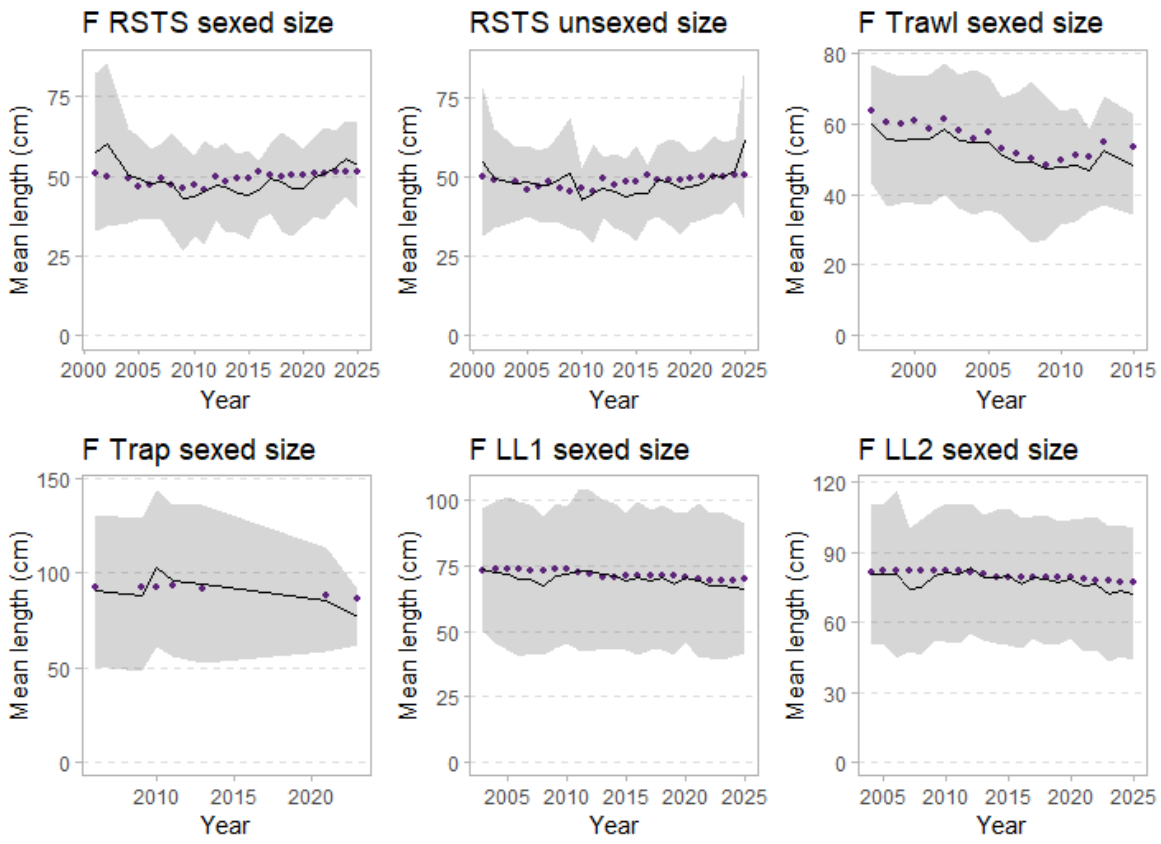


Figure 8: Predicted (points) versus observed (median and 95th percentile, line and shaded area) mean length female fish for each of the fisheries in the assessment, along with unsexed fish from the RSTS.

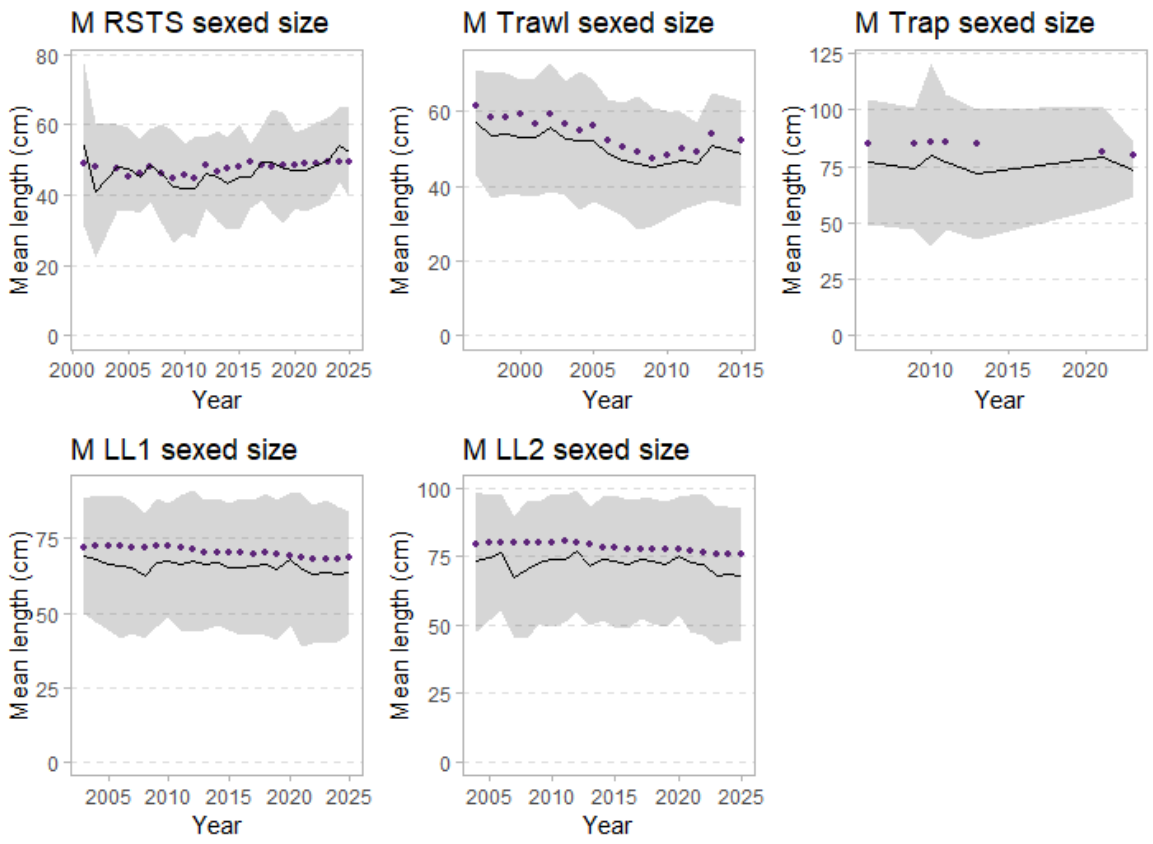


Figure 9: Predicted (points) versus observed (median and 95th percentile, line and shaded area) mean length male fish for each of the fisheries in the assessment.

Trends in predicted mean age at length appeared to differ by sex. For females, mean age at length tended to be underestimated prior to 2016 for both LL1 and LL2, however showed relatively good fit from this point until present (Figure 10, Figure 11; left). A similar trend was evident for female fish caught in the RSTS although better fits were seen from 2015 onwards (Figure 12; left). Reasonable fits were seen throughout the time series for trawl (Figure 14; left). Although primarily within the confidence bands, fits to trap showed slightly different trends in slope (Figure 13; left). For males, the trends in mean age-at-length show similar features to the females with respect to pre- and post 2016 differences, but marginally less so (Figure 10, Figure 11, Figure 12, Figure 13, Figure 14; right).

There is in apparent tension between the commercial length data and the sub-sample of these data that have been aged. The trend itself was consistent across sexes, to fit better to the length data in terms of mean length comes at the expense of getting a consistently unbiased estimate of mean age-at-length. The data weighting found a balance between these two, but it cannot completely ameliorate the problem, which arises from apparent model misspecification.

We have two probable (and possibly interacting) hypotheses for this conflict between the commercial length and age-at-length data:

1. The fish that are aged do not have the same length distribution as those that are caught across the whole fishery - there is inherent sub-selection of fish to age by design. This means that the prior age distribution, given selectivity and abundance-at-age, will differ between the length data and those fish with estimated ages. This results in selectivity estimates that trade off fit to one data set, at the expense of fit to the other
2. There is a more nuanced relationship between spatial distribution, fishing effort, length, age and sex on both the plateau and the shelf. This combination could interact to result in data whose joint age-length distribution differs from the aggregate length distribution observed in the commercial catches, leading to a conflict in the data when they are assumed to have the same selectivity/availability relationship

The data weighting has resulted in a solution that attempts to minimise this effect without eliminating it in either data set. The mismatches are unlikely to have a large impact on the assessment results, and indeed the λ weighting sensitivities strongly supports this hypothesis given the minimal impact on stock status when up/downweighting the length/age-at-length data by equal multipliers. However, it is a reasonably clear model misspecification that can be explored in future assessments using different selectivity functions for fish measured commercially for length and the subset of those fish that are aged. Data weighting factors used for each of the datasets are shown in Table 12.

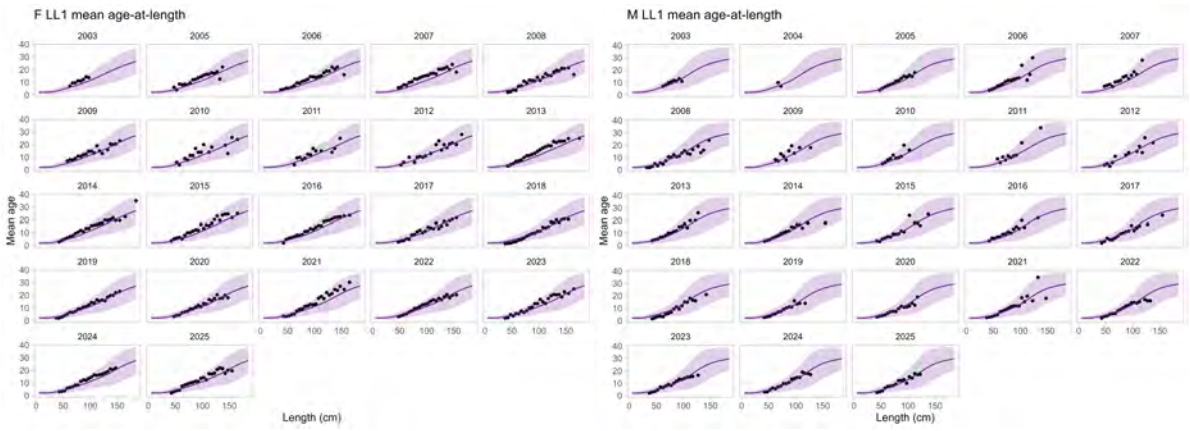


Figure 10: Fits to the LL1 (<1500m longline) age-given-length data for females (left) and males (right). Points are the observed mean age, and the lines and shaded area are the predicted median and 95th percentile. See Table 3 for annual sample sizes.

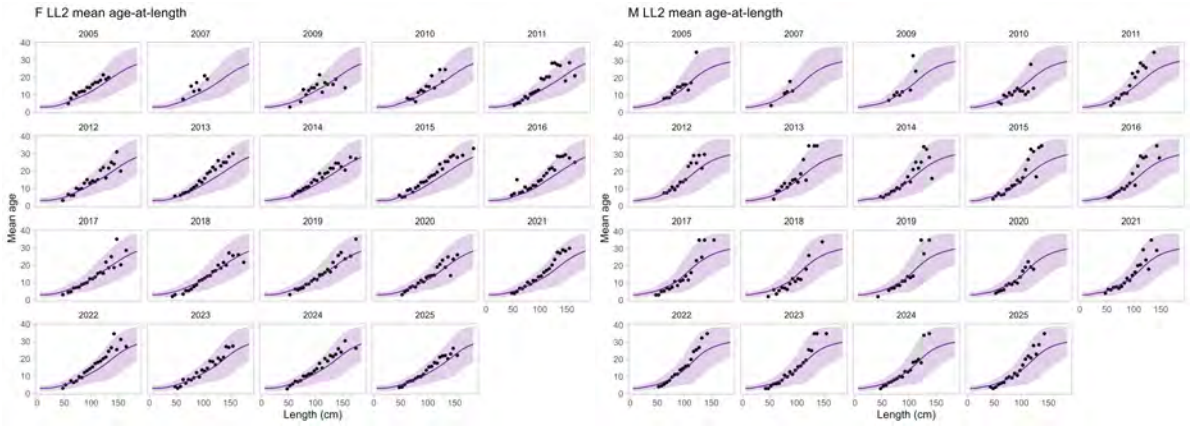


Figure 11: Fits to the LL2 (>1500m longline) age-given-length data for females (left) and males (right). Points are the observed mean age, and the lines and shaded area are the predicted median and 95th percentile. See Table 3 for annual sample sizes.

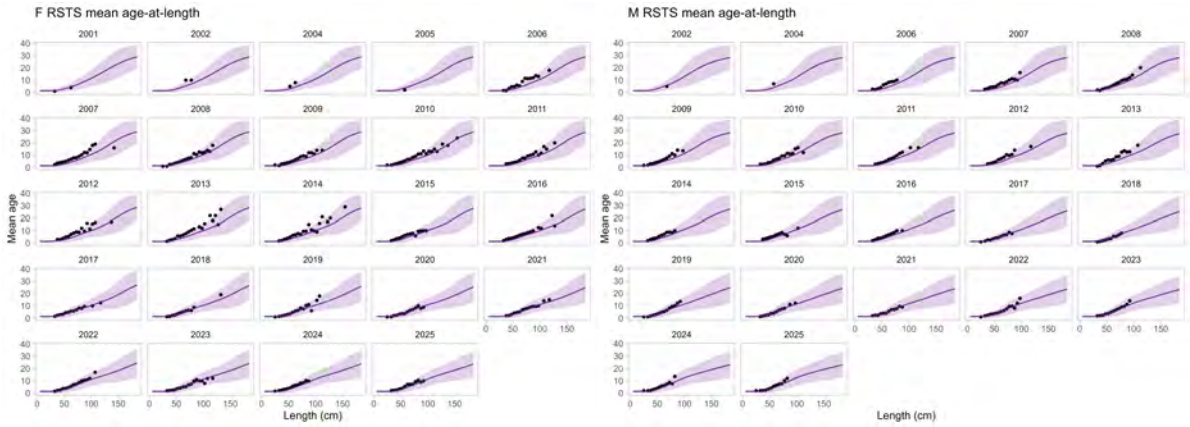


Figure 12: Fits to the RSTS age-given-length data for females (left) and males (right). Points are the observed mean age, and the lines and shaded area are the predicted median and 95th percentile. See Table 3 for annual sample sizes.

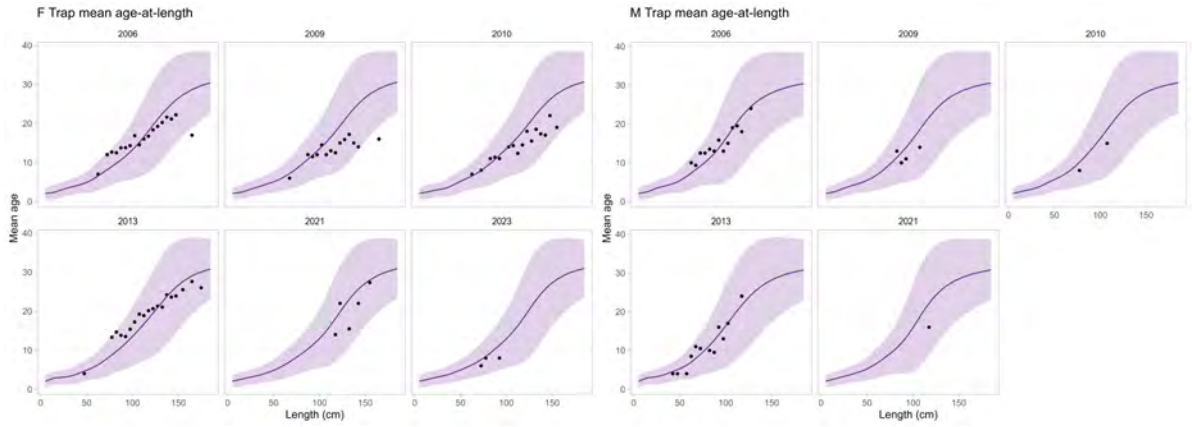


Figure 13: Fits to the trap age-given-length data for females (left) and males (right). Points are the observed mean age, and the lines and shaded area are the predicted median and 95th percentile. See Table 3 for annual sample sizes.

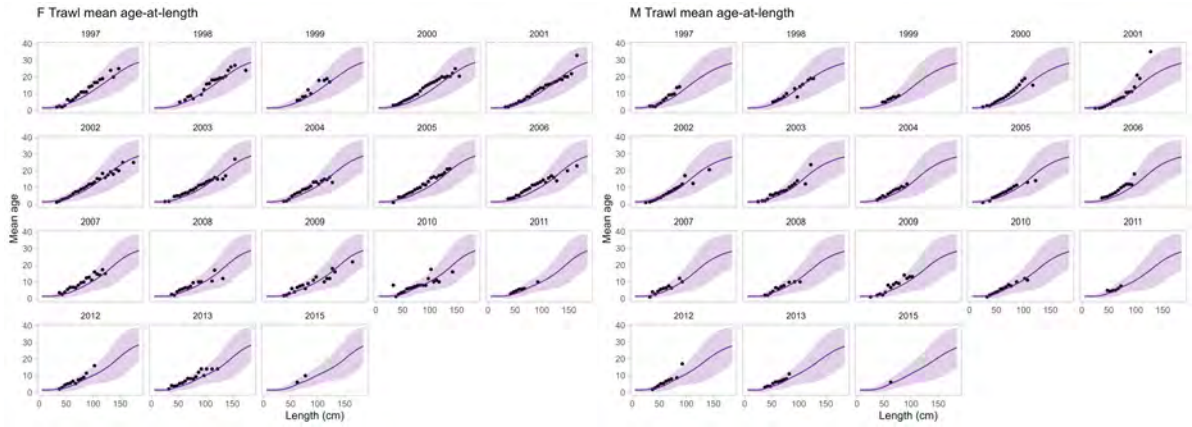


Figure 14: Fits to the trawl age-given-length data for females (left) and males (right). Points are the observed mean age, and the lines and shaded area are the predicted median and 95th percentile. See Table 3 for annual sample sizes.

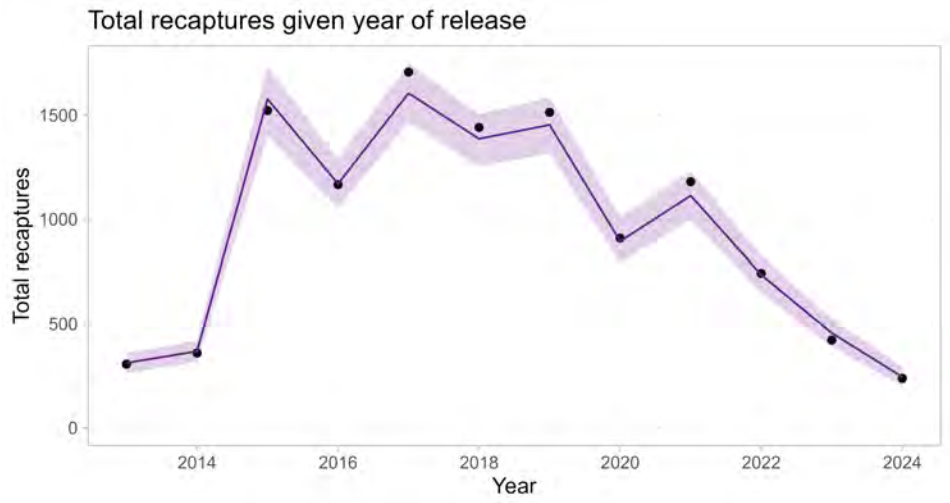


Figure 15: Posterior predictive interval (line and shaded region) and observed (points) overall tag recaptures for each release year on the shelf.

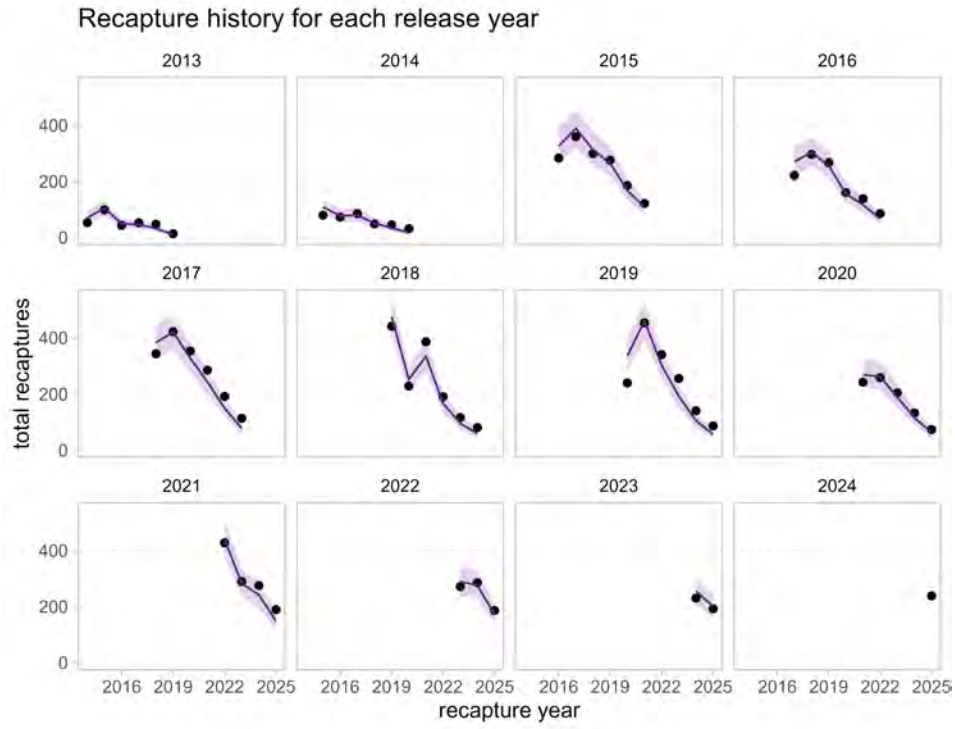


Figure 16: Posterior predictive interval (line and shaded region) and observed (points) tag recaptures for each release year on the shelf.

Fits to the shelf longline tagging data in terms of total recaptures by release year and by release and recapture event can be found in Figure 15 and Figure 16, respectively. In terms of total recaptures per release year, the model explains these data fairly well with all the data points contained within the predictive 95% interval at the MPD and no consistent trends over time. At the release and recapture level the model again struggles to completely explain the low numbers of recaptures in the first year of possible recapture for 2015, 2016, 2017 and 2019 but captures the key dynamics of the later release events and for the years in which recapture numbers are highest. Again, this still suggests some measure of model misspecification in the earliest time periods post-release that requires addressing in future stock assessment development.

Overall, the two-area model has managed to accommodate both the RSTS index and the tagging data and reduce the strong conflict between these data seen in previous non-spatial models. Moving to using both length and age-at-length data has removed the need for developing possibly noisy spatial and sex specific ALKs but we do see some apparent conflict between these data that the data weighting step cannot fully resolve at present.

7.3 Likelihood profiles

The likelihood profile for the reference model is shown in Figure 17. The contributions to the log likelihood provide a useful means of considering how consistent different data sources are with the MPD estimate of R_0. How closely the information from a particular data source aligns with the MPD estimate is indicated by how closely the minima is to the MPD value (the dashed vertical line). The more informative a data source, the steeper the gradient around the minima. In Figure 17, the tagging data supports a slightly lower value of R_0 than what was estimated, while the biomass index and length data support a much higher value.

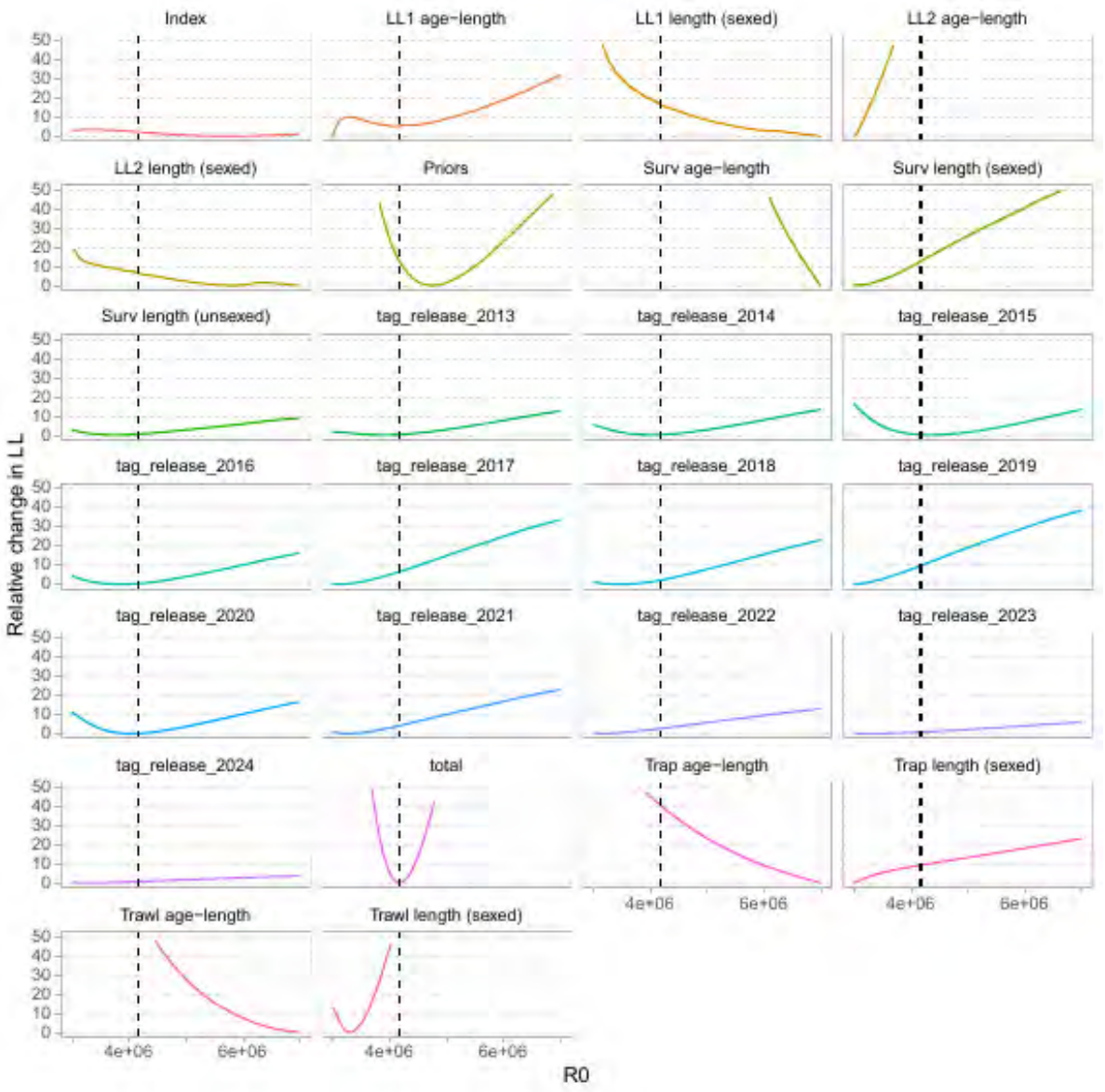


Figure 17: The change in contribution to the reference model objective function for each component of the integrated likelihood across a range of R_0 values. The MPD estimate for R_0 for this model is 4,217,120.

7.4 Sensitivity analyses

A number of sensitivity analyses were run to provide context for the robustness and key influences on estimates derived from the reference model (Table 9). Sensitivity runs (a)–(d)

are ones that are run each stock assessment, relating to alternative assumed values of natural mortality and the steepness of the stock-recruit relationship. Run (e) is where we estimate the recruitment deviations from 1988 to 2019 instead of 2017 as in the reference model. Run (f) is where time at liberty for the tag data is extended to 9 years, rather than 6 years which was used in the base case. Runs (g)–(j) are the λ-weighting runs where, using the data weighted reference model, we then arbitrarily down-weight a single data set by a multiplicative factor of 0.5 to see how well the balanced reference model reacts to an additional data weighting changes. Run (k) includes the revised SIOFA catches which were incorrect in the original assessment and model runs. Summarising the sensitivity results:

- For the M and steepness scenarios we see consistent behavior with previous assessments, with changes in overall scale (i.e. SSB_0 and R_0) but very minimal change in stock status.
- For the additional recruitment years we see very little change in scale relative to the reference model, with a slightly more optimistic final status and lower RSTS q value. This run resulted in a high estimated recruitment deviation in 2018 and while this is well estimated, it has only been observed in the data in the survey and not in the commercial fishery data. Additional diagnostics for this run are included in the appendix.
- For the run with additional years of tag-recapture data included in the assessment, estimates of SSB_0 and stock status were similar to the reference case, although the estimate of R_0 was marginally lower. Additional diagnostics for this run are included in the appendix.
- For the λ-weighting runs we see very little meaningful change in either scale or status, with the largest variation being observed in survey catchability, q.
- For the run with amended SIOFA catches, estimates of stock status were the same as the reference model, with very small increases in estimates of SSB_0 and R_0.

Table 9: MPD results of reference model and sensitivity analyses, with estimates of unfished spawning stock biomass SSB_0 in tonnes, SSB status at the end of 2026, R_0 (mean recruitment in millions that gives rise to SSB_0), survey catchability q, and the number of estimated parameters (N Parameters).

Sensitivity run	SSB_0	SSB status	R_0	Survey q	N Parameters
Reference	77858	0.42	4.22	1.82	131
a) $M = 0.1379005$	98123	0.44	3.85	1.95	131
b) $h = 0.6$	80894	0.41	4.38	1.85	131
c) $h = 0.9$	75797	0.43	4.11	1.82	131
d) $h = 0.9$, $M = 0.13$	107975	0.46	3.62	1.98	131
e) Last rec. dev. 2019	76411	0.43	4.14	1.68	133
f) tag data 9 yrs. at lib.	76037	0.42	3.88	1.86	179
g) lambdaRSTS	77450	0.42	4.19	1.82	131
h) lambdaLF	75205	0.43	4.07	1.55	131
i) lambdaALF	80734	0.43	4.37	2.04	131

Table 9: MPD results of reference model and sensitivity analyses, with estimates of unfished spawning stock biomass SSB_0 in tonnes, SSB status at the end of 2026, R_0 (mean recruitment in millions that gives rise to SSB_0), survey catchability q, and the number of estimated parameters (N Parameters).

Sensitivity run	SSB_0	SSB status	R_0	Survey q	N Parameters
j) lambdaTags	80020	0.43	4.33	1.77	131
k) revised SIOFA catches	78387	0.42	4.25	1.82	131

Detailed results and model fits for sensitivity runs (e) in Figure 39–Figure 42 and (f) in Figure 43–Figure 46.

7.5 Retrospective analysis

A retrospective analysis for SSB, depletion, recruitment deviations and harvest rates is shown in Figure 18, with successive years of data removed from the assessment. This analysis was completed using MPD estimates. The results show that SSB, stock status and harvest rates are generally revised downwards as additional years of data are included in the assessment. This trend is less evident between 2025 and 2023 than in 2022 and 2021 (Figure 18). The estimated recruitment deviations are also revised downwards from around 2010 onwards as additional years of data are included in the assessment (Figure 18). The retrospective patterns illustrated here are much smaller than those observed in the previous assessment (Masere and Ziegler 2024).

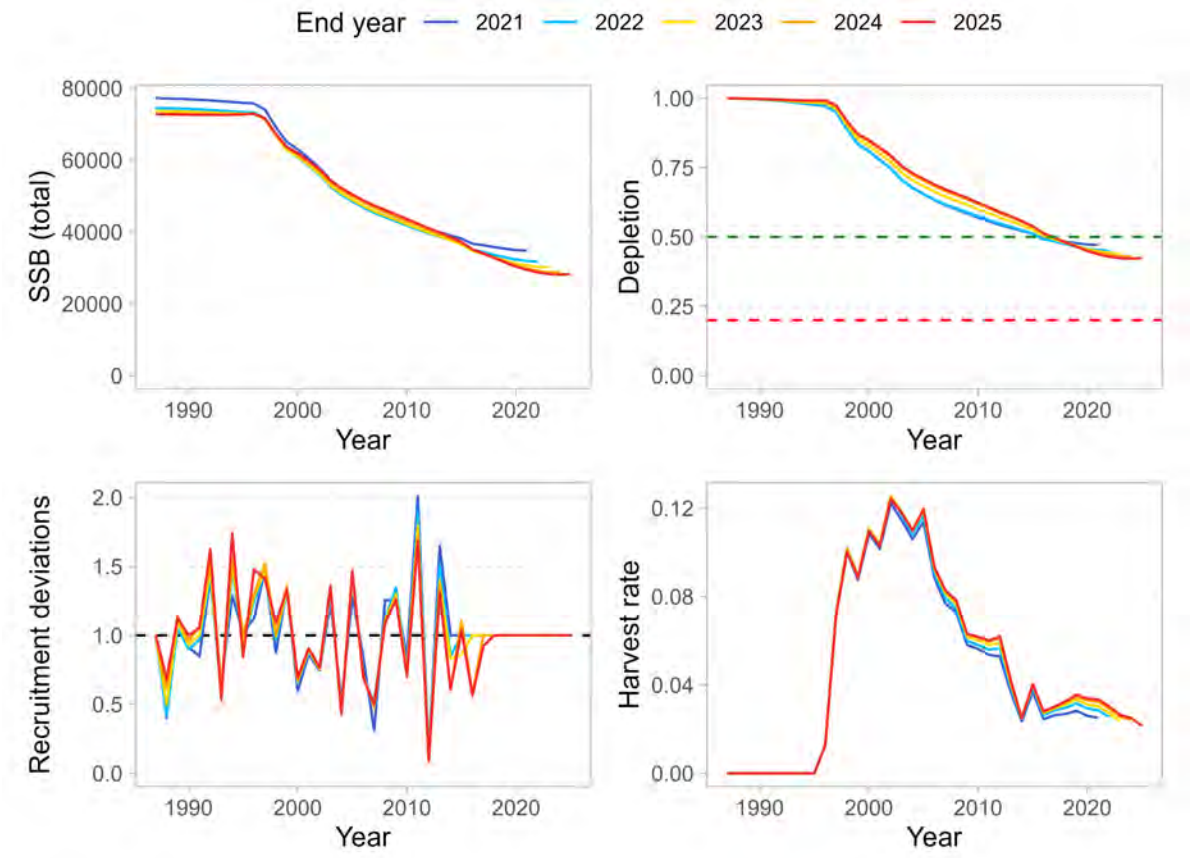


Figure 18: Retrospectives for *SSB*, depletion, recruitment deviations and harvest rates for the reference model assessment with data included to 2025 and then successive years removed back to 2011.

7.6 MCMC estimates

The base two-area model leads to MCMC-derived estimates of virgin spawning stock biomass SSB_0 of 77,859 (95% CI: 75,738–80,280 tonnes). The estimated SSB status at the end of 2025 was 0.424 (95% CI: 0.411-0.436) (Table 10). Current SSB trends are almost flat (Figure 19), as opposed to the downward trend observed in the 2024 assessment. The estimate for q is notably higher with a median of 1.82. Recruitment shows a more balanced and random looking pattern than observed in than observed in the single-area sex-aggregated model (Figure 20). They are still slightly higher pre-2000 (before the data would be more influential), but patterns are improved compared to previous model configurations.

Table 10: MCMC results (median and 95% confidence intervals) for SSB_0, SSB status and survey q.

Model	SSB_0	Current SSB Status	Survey q
2023 Assessment	64 520 (60 419 – 69 241)	2023: 0.39 (0.39 – 0.40)	1.08 (0.95 – 1.24)
2024 Assessment	64 083 (60 139 – 68 635)	2024: 0.38 (0.38 – 0.38)	1.22 (1.04 – 1.43)
2026 Assessment	77 859 (75 738 – 80 280)	2026: 0.42 (0.41 – 0.44)	1.82 (1.71 – 1.95)

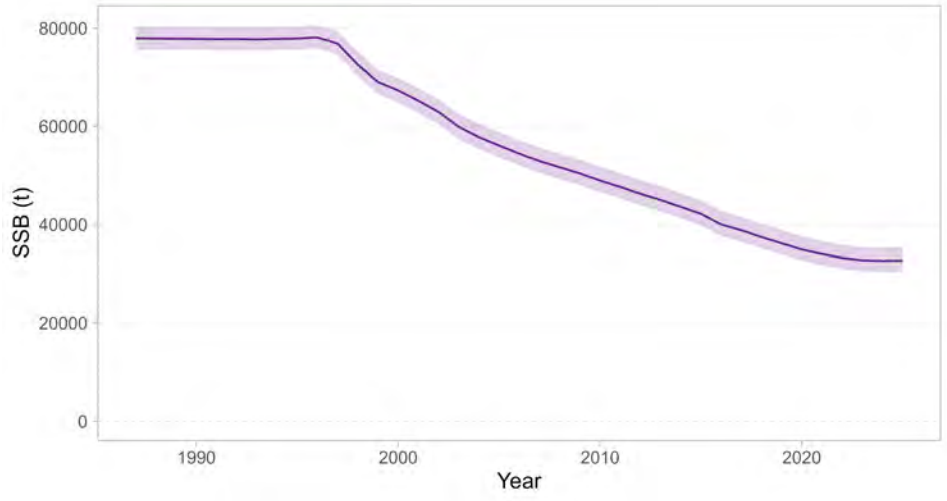


Figure 19: Estimated trajectory of SSB for the reference model showing the median (line) and 95% credible intervals (shaded area).

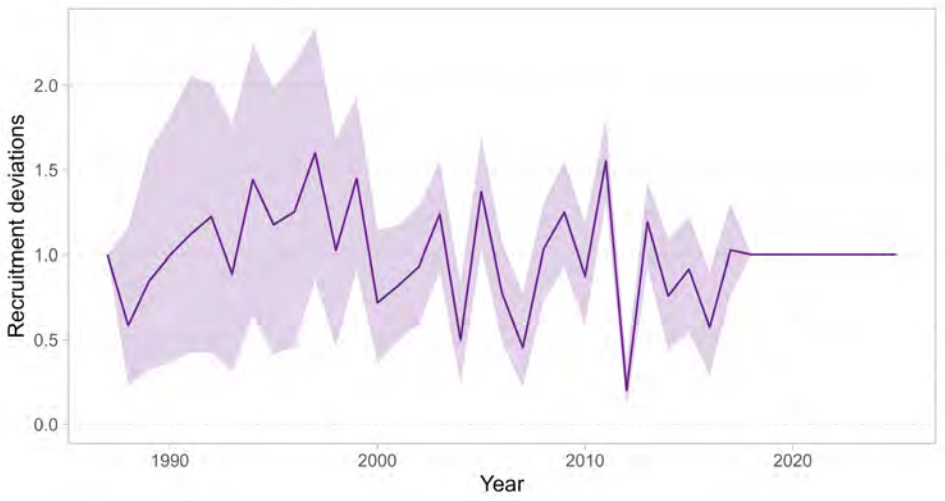


Figure 20: Estimated recruitment deviations for the reference model showing the median (line) and 95% credible intervals (shaded area). Recruitment deviations are estimated from 1988–2017.

In terms of selectivity summaries we first focus on the time-invariant fishery selectivities: RSTS, trap, LL1 and LL2. The RSTS selectivity-at-length is assumed to be 1 across all lengths so is not graphically summarised. The other three time-invariant selectivity-at-length relationships are detailed in Figure 21. For the trawl fleet we assume a time-varying relationship whereby the length at which the selectivity smoothly switches to full selectivity undergoes a random walk over the years for which there are length and age data (1997–2015). In Figure 22 we plot the posterior summary for the estimated length at which selectivity shifts to full selection.

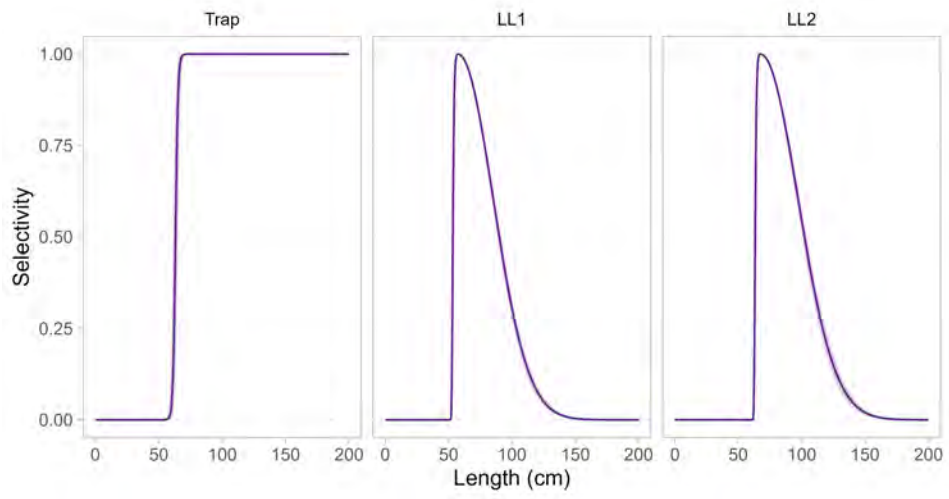


Figure 21: Median (line) and 95% credible interval (shaded area) region for the selectivity-at-length relationships for the trap and longline fisheries.

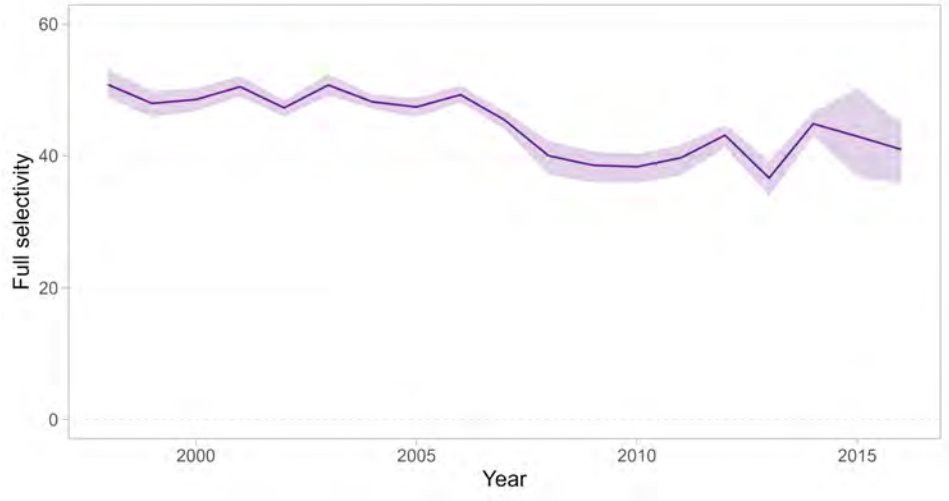


Figure 22: Median (line) and 95% credible interval (shaded area) region for the length at which the trawl shifts to full selection.

For the reference model we have time-independent but length-specific movement probability from the plateau to the shelf. This relationship is logit-linear and can be flat, increasing or decreasing with length as required and has two estimated parameters. In Figure 23 we plot the posterior summary of this plateau-to-shelf movement probability. The relationship shows a clear declining relationship in movement probability-at-length, and the relationship is more certain within the 40–80cm range simply because the vast majority of the fish on the

plateau are within this range. A slightly declining relationship with length, while not simply counter-intuitive, is perhaps indicative of at least two possibilities:

- That this movement is a proxy for a more complicated process around spatial distribution-at-length on the plateau
- That movement may be a more length-specific diffusive process. Specifically, a general but continuous time random drift into deeper waters as fish grow where the diffusion coefficient is itself decreasing with depth. This would manifest in a decreasing bulk movement probability-at-length in a very simple box model such as this, simply because longer fish are forever moving closer to the arbitrary and not perfectly well defined border we have assumed between the plateau and the shelf

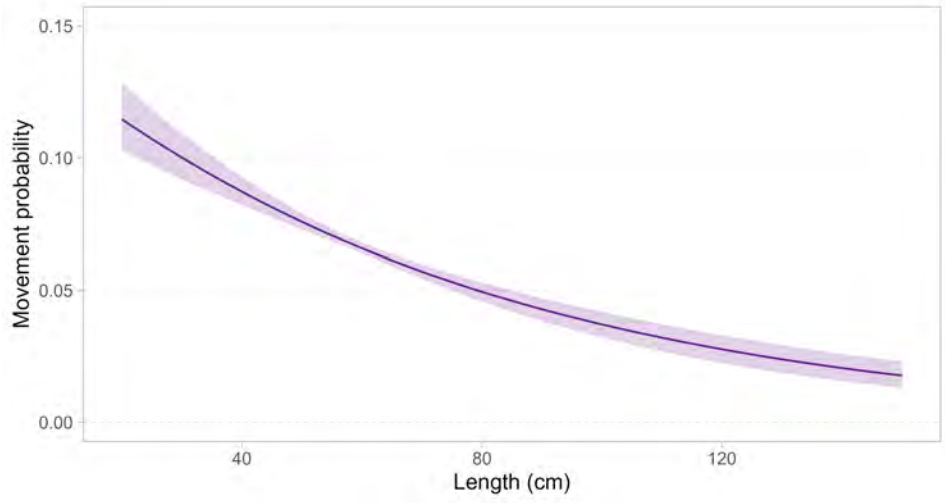


Figure 23: Median (line) and 95% credible interval (shaded area) region for the probability-at-length for moving from the plateau to the shelf.

7.7 Calculations of catch limits

For the purposes of projections, recruitment deviations were sampled from a user-defined set of years within each MCMC sample and used to generate future recruitment. A historical average of the most recent four years was used to calculate the future catch split between fisheries.

Following the CCAMLR decision rules, the yield for the reference model was estimated to be 3,503 tonnes. Over the course of the projection period, the median SSB does not fall below the currently estimated level, and after a flat 10 year period begins increasing to the target level in 2035 and reaches the target level in a flat trajectory after 35 years (Figure 24).

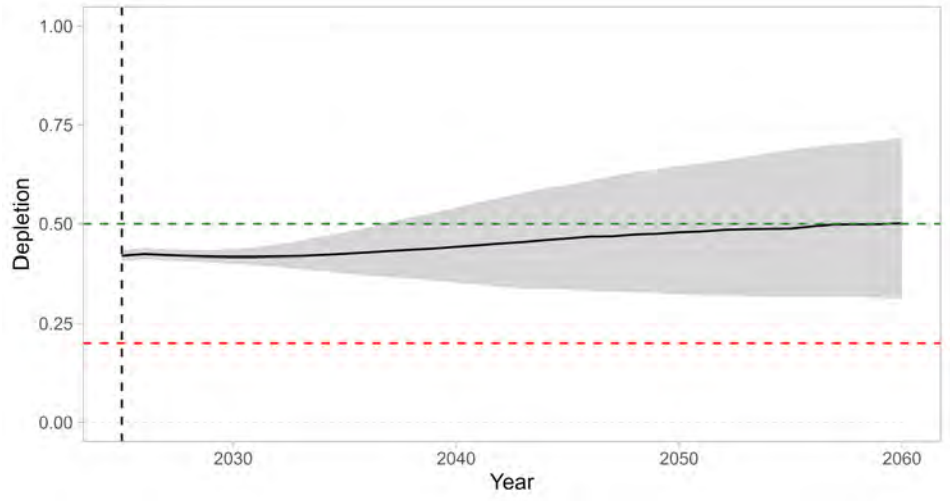


Figure 24: Projected SSB status under the TAC estimated from the CCAMLR rule for the reference model showing the median (line) and 95% simulation interval (shaded area). The red, dashed line is the limit reference point and the green, dashed line is the target reference point.

7.7.1 Sensitivity of recruitment assumptions to catch limits

The impact of alternative assumptions about future recruitment were investigated to determine the sensitivity of the assessment to these choices. In addition to the reference model (sampling recruitment deviations from 1988–2017), a model where recruitment for the projections was sampled from a shorter time period (1998–2017) was undertaken, along with the sensitivity run (e), where recruitment deviations were estimated from 1988–2019 in the reference model and projections sampled recruitment from this same period and senstivity run (k) where the revised SIOFA catches were included.

Results from Table 11 show the impact of the assumptions about recruitment when applying the CCAMLR decision rules. When only sampling recruitment from the shorter time period a lower catch limit is estimated, as some of the above average early recruitment deviations have been excluded. When re-sampling from recruitment deviations estimated to 2019, rather than 2017, the catch limits are higher, as there is a large above average recruitment deviation estimated in 2018. Table 11 also demonstrates the marginally higher catch limit estimated when including the revised SIOFA catches in the assessment.

Table 11: Estimates of catch limits in tonnes based on MCMC sampling that satisfy the CCAMLR decision rules, with (i) the median escapement of the spawning biomass at the end of the 35-year projection period ('Target'), and (ii) the risk of the spawning biomass dropping below 20% of its median pre-exploitation level at any time over the 35-year projection period ('Depletion'). Results are shown for the reference case, a model with projections sampled from 1998–2017 and 1988–2019 and sensitivity run (k) with revised SIOFA catches.

Model	Rec dev years	Catch limit	Target	Depletion
Reference	1988-2017	3503	0.5	<0.01
	1998-2017	3043	0.5	<0.01
	1988-2019	3658	0.5	<0.01
Sensitivity (k)	1988-2017	3544	0.5	<0.01

7.7.2 Calculation of the constant harvest rate multiplier and associated catch limit

We calculated the long-term exploitation rate proxy U, where $C = U * SSB$, that would result in the probability of SSB depletion to be least 0.5, with a probability of being above 0.2 of at least 0.9. Using a 50 year projection to ensure stochastic equilibrium is reached the estimated value was $U_{50} = 0.094$. In Figure 25 we plot the SSB depletion projections, using all the historical recruitment deviations to generate future values, for the estimated U_{50} over a 50 year period. Using the most recent stock assessment median SSB estimate from the MCMC the associated catch limit would be 3,097 t. Over the first 35 years of the projection period the average catch using the estimated U_{50} was 3,480 t.

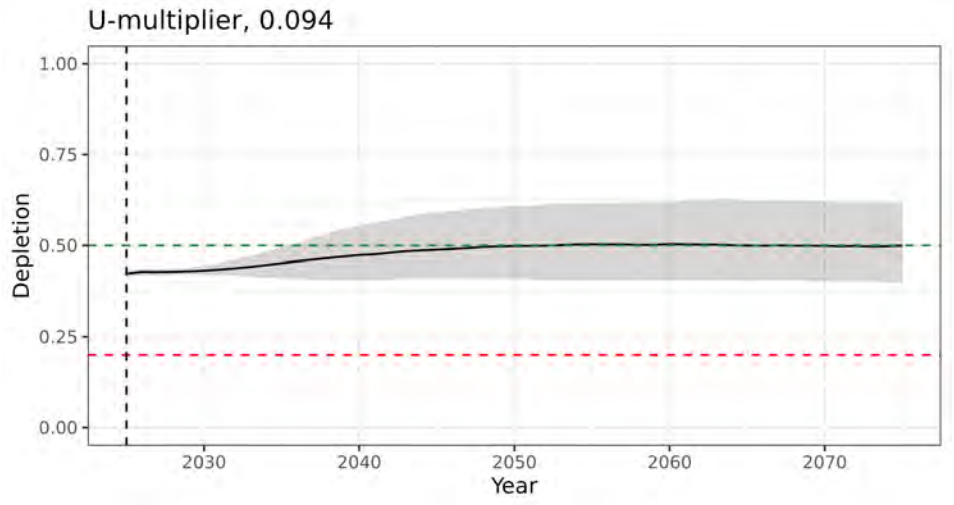


Figure 25: Projected *SSB* status under the estimated harvest rate proxy showing the median (line) and 95% simulation interval (shaded area). The red, dashed line is the limit reference point and the green, dashed line is the target reference point.

8 Discussion

The 2026 stock assessment is the first attempt at a spatially and sex-structured integrated population dynamics model for the Patagonian toothfish fishery at HIMI. Previous assessments have struggled to fit to both the RSTS survey index and the mark-recapture data so a number of structural changes have been explored to work towards solving this fundamental problem, these have included:

- Spatially structure the population and fishery into two parts: (i) the plateau where recruitment occurs, and the RSTS and trawl fisheries are located; and (ii) the shelf where fish must migrate to as they grow and where the longline and trap fisheries are located and the tagging data are collected from.
- Explicitly model the movement of fish, including potential length-dependence, from the plateau to the shelf
- Use a process error approach to accommodate the tag mixing issues apparent in the first few years of recapture for some release years

In addition to these there have been several changes made to how key fishery and biological relationships and data sets are handled, these include:

- Maturity is modelled by length, utilising the vast amount of maturity staging data and is done separately for males and females

- Sex-specific growth is estimated using a conditional age-at-length approach that accommodates both length-selectivity and ageing error effects
- Selectivity relationships are parameterised in terms of length, not age, and are then filtered through the length-at-age distribution
- Instead of annual age-length keys (ALKs) both length and conditional age-at-length are included in the model
- The tagging data are modelled using a Brownie approach where uncertainty in release length and sex is fully integrated into the likelihood
- The tag shedding relationship has been updated for the most recent data and an instantaneous-then-exponential double-tagged shedding model replaces the linear relationship used in previous assessments

The 2026 WG-SAM meeting reviewed and endorsed the general approach we have taken and made several recommendations for this work, which have subsequently been incorporated into this assessment. The assessment is more complex than previous iterations but has managed to solve the key issue of being able to fit to both the RSTS index and the tagging data. Additionally, the previous trend in recruitment deviations has largely disappeared. There is still an apparent effect of having some lower estimates more recently, but they still vary around the mean level of one and look much more random than seen in previous assessments. This improves our confidence that the current model specification resolves at least some of the mis-specification issues that were present in previous iterations (of which the recruitment time-series appeared to have been an indication). It also improves confidence in the projections used to calculate the recommended catch limits via the CCAMLR decision rules.

Outputs from the stock assessment suggest a stock status of 0.42 as of 2025, and a TAC of 3,503 t based on the CCAMLR decision rules. The array of sensitivity runs (Table 9) suggest that the stock status outcomes are consistent across alternative values for various key biological parameters, data-weighting scenarios, the estimation of additional recruitment deviations, and including longer tag recapture histories. Projections are still somewhat dependent on how historical recruitment estimates are used to generate future values. The future MSE workplan is the most appropriate place to deal with these issues in a consistent manner as alternative management strategies and future population dynamic and environmental scenarios are explored and evaluated.

While the model is able to accommodate the RSTS and the tagging data there are some clear model structure issues that remain. In particular, the tension between the commercial length data and the age-at-length data, particularly for the males more so than the females. For the trawl, trap (males only) and longline (males only) data we over-estimate the right-hand tail of the length distribution, and in some years we under estimate the mean length-at-age. We believe this stems largely from the fact that the ageing data length distribution is not the same as the commercially caught one. A non-random and wider length range is selected to be aged, resulting in differing length distributions. This issue manifests itself in the selectivity estimates for these fisheries, this key relationship is central to the calculation of both predicted length and age-at-length for each fishery. A potential solution to this issue is to have separate

selectivity relationships for fish that are caught commercially and those that are aged. We would include the length distribution of aged fish inside the model, as well as the commercial length data, which would hopefully avoid the conflict between these data. Also, we have explicitly imposed logistic selectivity for both the trawl and trap fisheries, but as can be seen in Figure 29, Figure 30, Figure 31, Figure 30, particularly for the males, we often have a bias in the right-hand side of the fitted length distribution predicting longer fish in the catch than observed. In future models we will explore dome-shaped selectivities for these fisheries.

There may also be additional complex sex-age-length spatial effects that contribute to this apparent issue. Future assessments with more spatial regions and sex-specific model features can explore this hypothesis, but also the MSE work can begin looking at this directly. One would expect to be exploring more detailed spatial configurations within that work. This should arguably include explicit scenarios that look at the potential effect of these more nuanced spatial and sex-specific effects which may give insights into how best to model them within future assessment models.

The estimated value of catchability, q, is higher than has previous been estimated in HIMI stock assessments (MPD value = 1.81, MCMC value = 1.81). While it is important to consider the magnitude of this estimate, the interpretation of this value in this setting is somewhat more ambiguous than in the spatially aggregated case, especially given the limited overlap between the RSTS survey and the areas within HIMI where longline operations occur. Some of this difference may reflect additional patchiness in the habitat not captured by the swept area estimator. Some may be attributable to the simplistic spatial definition used in this model that does not reflect the more nuanced overlap between "plateau" and "shelf" fisheries and their respective outer limits. Also, some may be attributable to the swept area construction of the index itself. If there is more heterogeneity in viable habitat than currently assumed the swept area itself may be over estimated, which could lead to high biomass estimates, potentially leading to an elevated estimate of catchability within the model. To bolster the argument about interpretation in the sensitivity run summary table (Table 9), the survey catchability shows large variation across scenarios, even when population scale and in particular current status show relatively little variation in comparison. In future, given the context for needing a swept area absolute biomass index no longer applies (absolute biomass is informed primarily by the tagging data), future RSTS models might simply explore developing a relative abundance index, that not only obviates the need for a catchability that is interpreted in the "real" sense, but could reduce observation error also. It would also be a true reflection of how the index is actually treated in the model i.e. as a relative abundance index given catchability is a freely estimated parameter.

There are still unexplained trends in about half of the release years for the tagging data on the shelf. Specifically in the first year of recapture there are some release years where there is a lower than expected number of recaptures that quickly resolves itself into the expected tag attrition decreasing pattern. The process error approach used in the assessment deals with these trends without it causing issues within the model but it is not a mechanistic solution - it attributes the effect to a random process that decays over time, but it is more likely to

be a short-term tag mixing/effort overlap problem. Future work on the assessment model could look at adding a small number of regions to the shelf, and perhaps a tag/effort overlap covariate to determine if there is a more process-model solution to this trend in the recapture data. The sensitivity run that uses 9 years of recaptures, not just 6, demonstrates that these patterns are short lived and there is long-term tag mixing relative to the patterns in fishing effort.

This new assessment is the first major undertaking in a multi-year work program that includes a full Management Strategy Evaluation (MSE) process to develop a robust replacement for the current CCAMLR decision rule. For HIMI, this first tranche of MSE work is expected to be delivered to the 2027 CCAMLR meetings, with the next stock assessment expected to be delivered in 2028. This assessment implements key model features as advised by 2026 WG-SAM. The assessment framework implemented has allowed for a more realistic representation of Patagonian toothfish biology, ecology and fisheries, resulting in improved model diagnostics and resolution of key data conflicts compared to previous versions.

Acknowledgements

We would like to thank Tim Lamb, Carson Fisk, Dale Maschette, Andy Nicholls, Evan Leonard, previous AAD Fisheries team members, as well as all observers and scientists on board of fishing vessels for their support in providing data and undertaking work to underpin this assessment. Thanks also to the members of the Sub-Antarctic Resource Assessment Group for helpful comments on the Science. Components of this work were made possible through grants from the Australian Fisheries Research and Development Corporation (FRDC), the Australian Fisheries Management Authority (AFMA), and the Australian toothfish fishing industry.

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Appendix

Reference model diagnostics

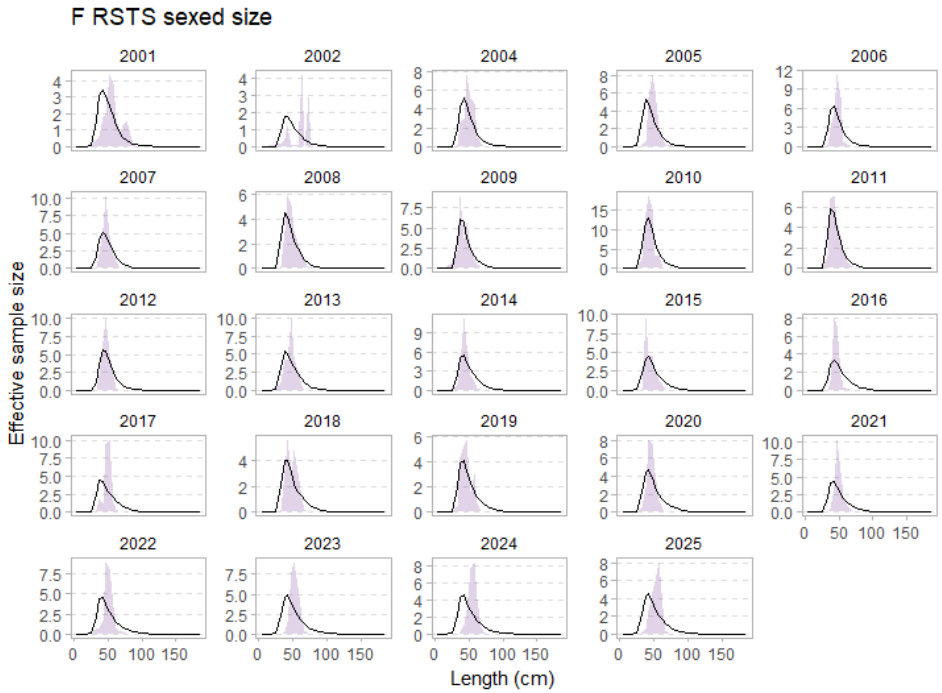


Figure 26: Fits to the RSTS female length data. Shaded area is the observed data, and the lines are the predictions.

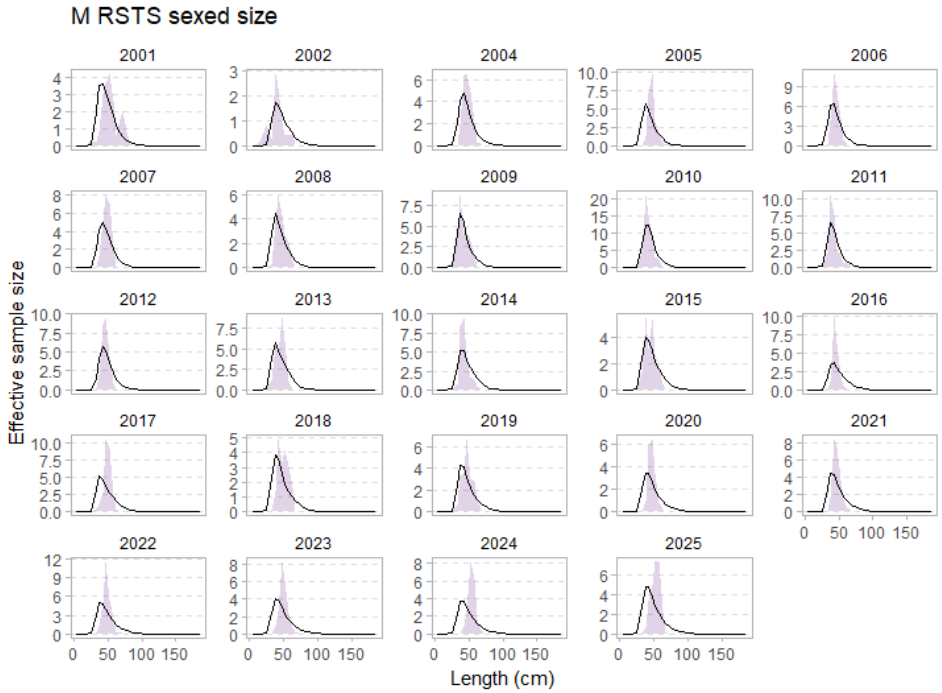


Figure 27: Fits to the RSTS male length data. Shaded area is the observed data, and the lines are the predictions.

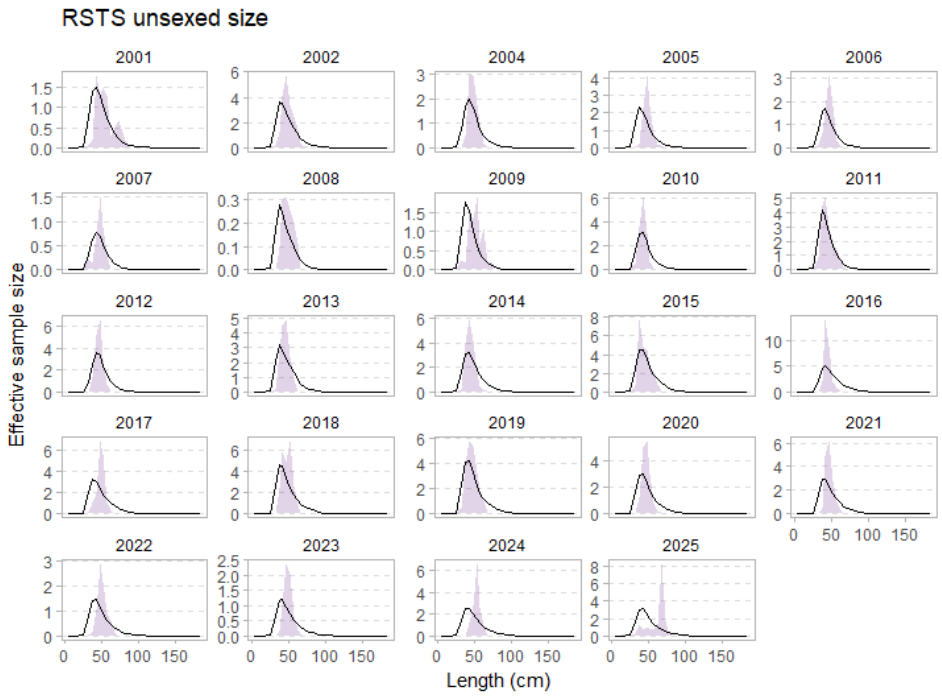


Figure 28: Fits to the RSTS unsexed length data. Shaded area is the observed data, and the lines are the predictions.

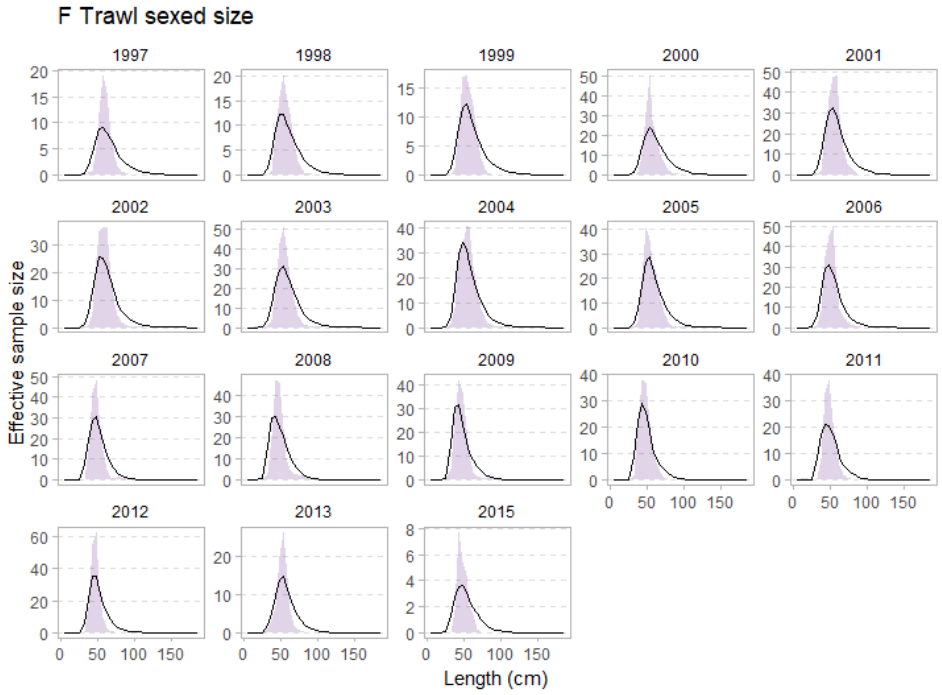


Figure 29: Fits to the trawl female length data. Shaded area is the observed data, and the lines are the predictions.

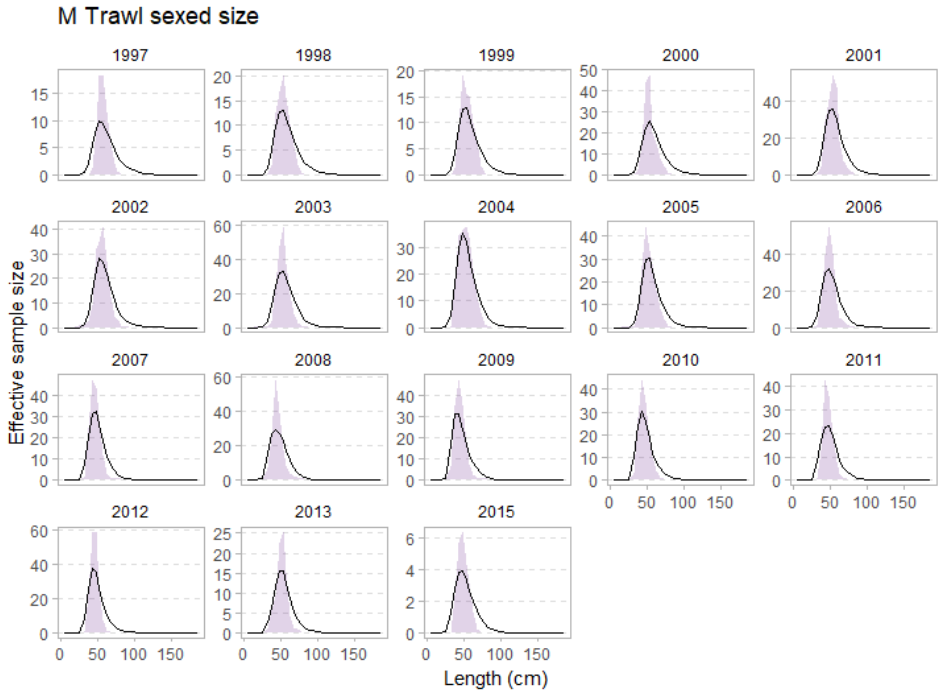


Figure 30: Fits to the trawl male length data. Shaded area is the observed data, and the lines are the predictions.

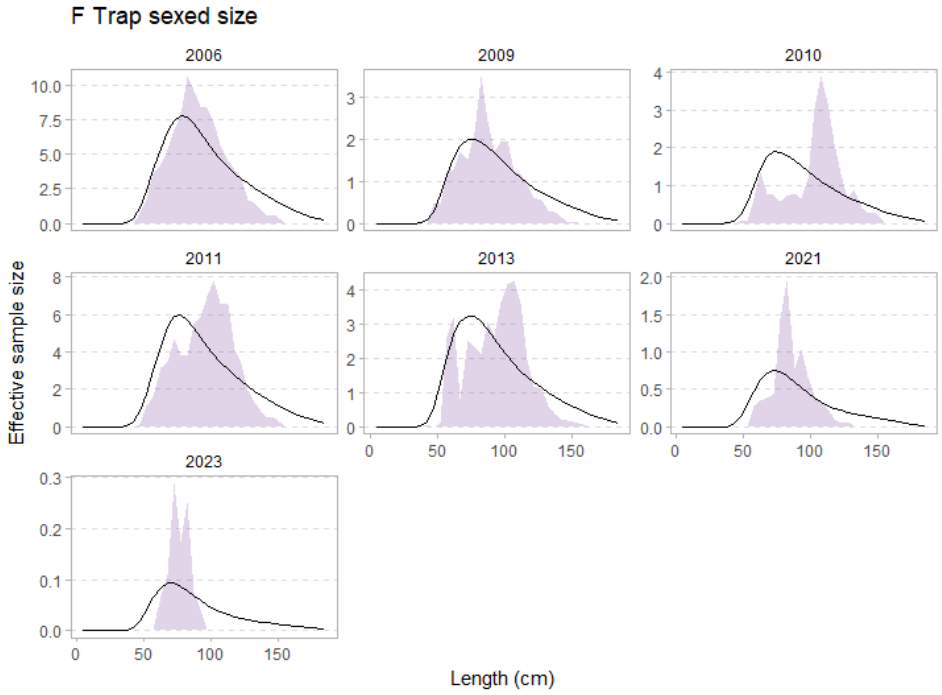


Figure 31: Fits to the trap female length data. Shaded area is the observed data, and the lines are the predictions.

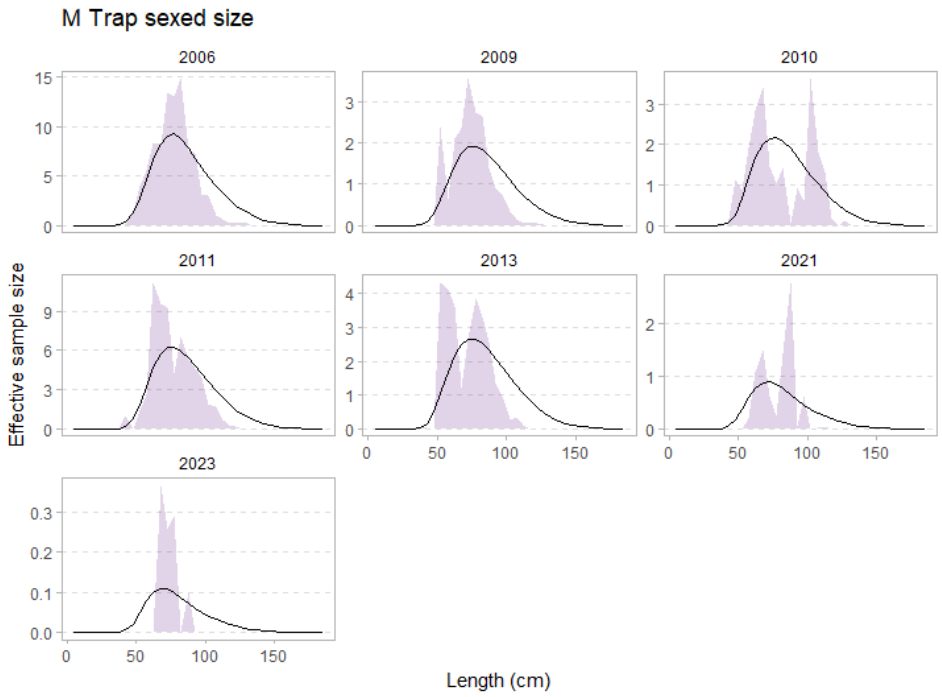


Figure 32: Fits to the trap male length data. Shaded area is the observed data, and the lines are the predictions.

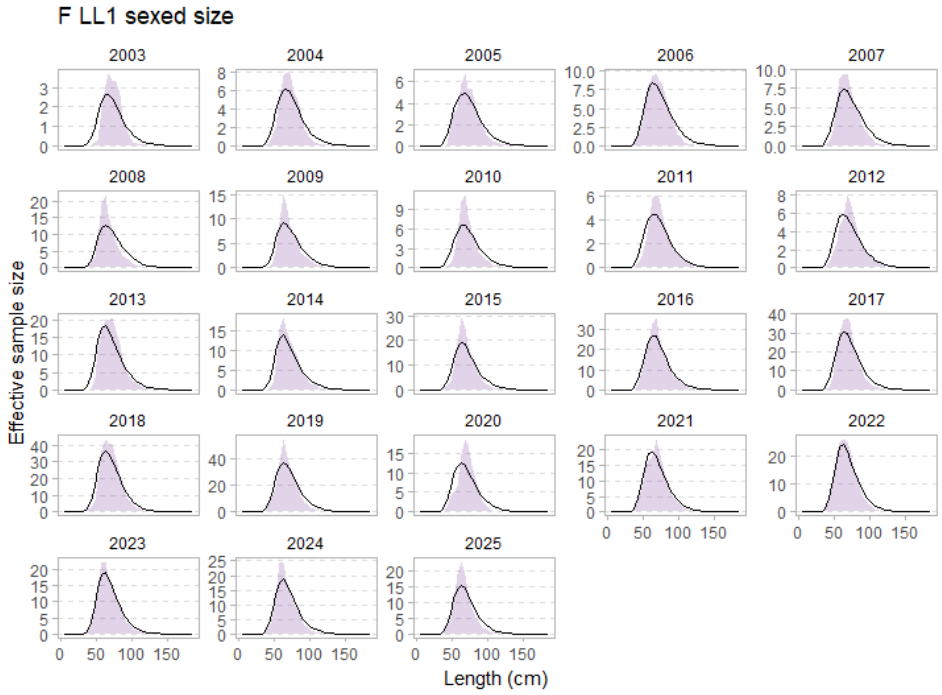


Figure 33: Fits to the LL1 female length data. Shaded area is the observed data, and the lines are the predictions.

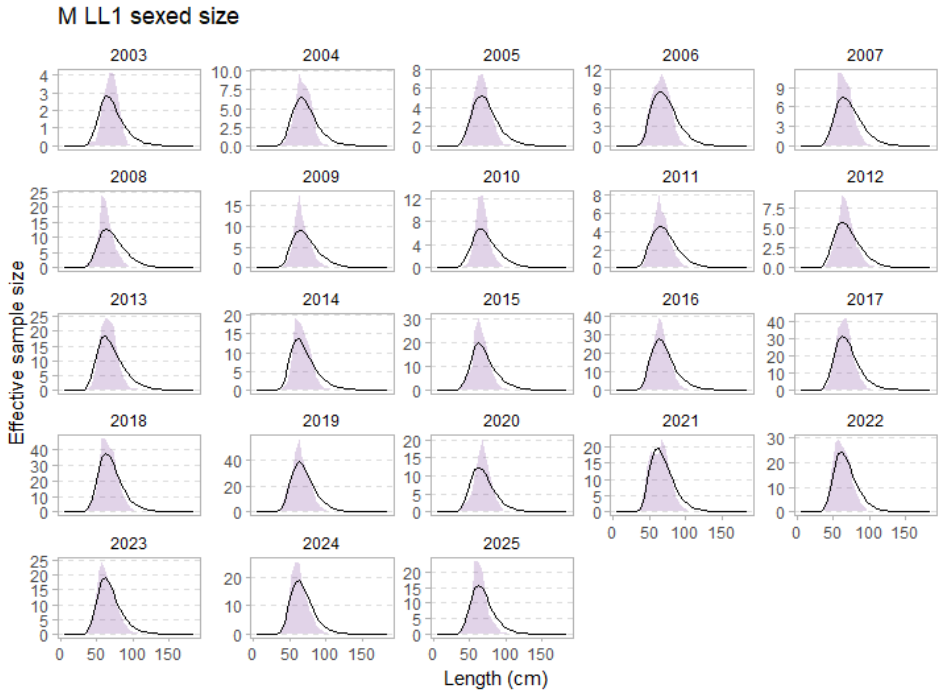


Figure 34: Fits to the LL1 male length data. Shaded area is the observed data, and the lines are the predictions.

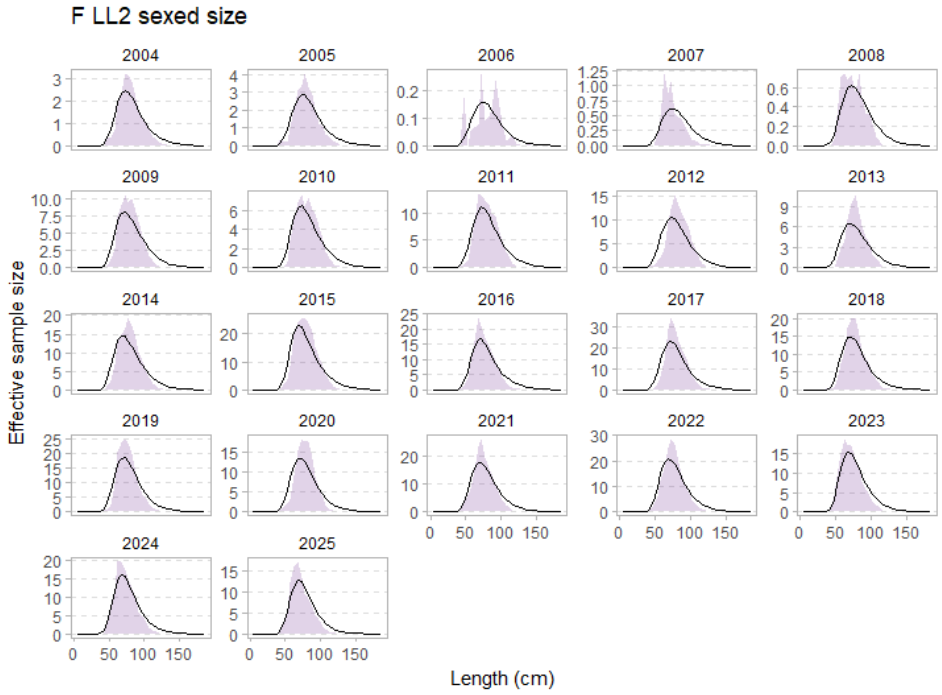


Figure 35: Fits to the LL2 female length data. Shaded area is the observed data, and the lines are the predictions.

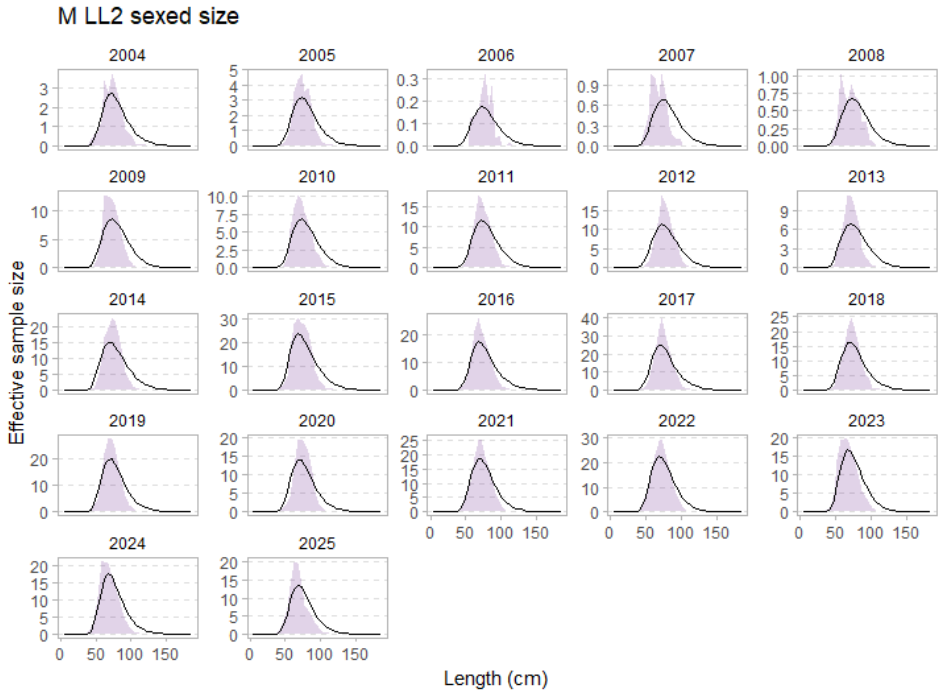


Figure 36: Fits to the LL2 male length data. Shaded area is the observed data, and the lines are the predictions.

Table 12: Data weighting factors used for length and age-at-length data by fishery and sex and overdispersion parameters estimated for the RSTS survey and the tag data

Data	Fishery	Female	Male	Unsexed
Length	RSTS	0.215	0.215	0.215
	Trawl	0.257	0.257	
	Trap	0.505	0.505	
	LL1	0.252	0.252	
	LL2	0.305	0.305	
Age-at-length	RSTS	0.086	0.081	
	Trawl	0.168	0.187	
	Trap	0.183	0.99	
	LL1	0.143	0.299	
	LL2	0.089	0.468	
Survey	RSTS			0.01
Tag	Shelf			0.91

MCMC diagnostics

Four chains with 1000 iterations each after a burnin of 300. No thinning, as recommended in standard HMC practice (Stan Development Team 2026). Figure 37 shows the trace plots for the key population parameters and Figure 38 shows the $\hat{R}$ diagnostic for chain mixing. All chains appear to be stable, with no evidence of strong autocorrelation and chains are well mixed ($\hat{R} < 1.05$). In addition all effective sample sizes (N_{eff}) were greater than 400.

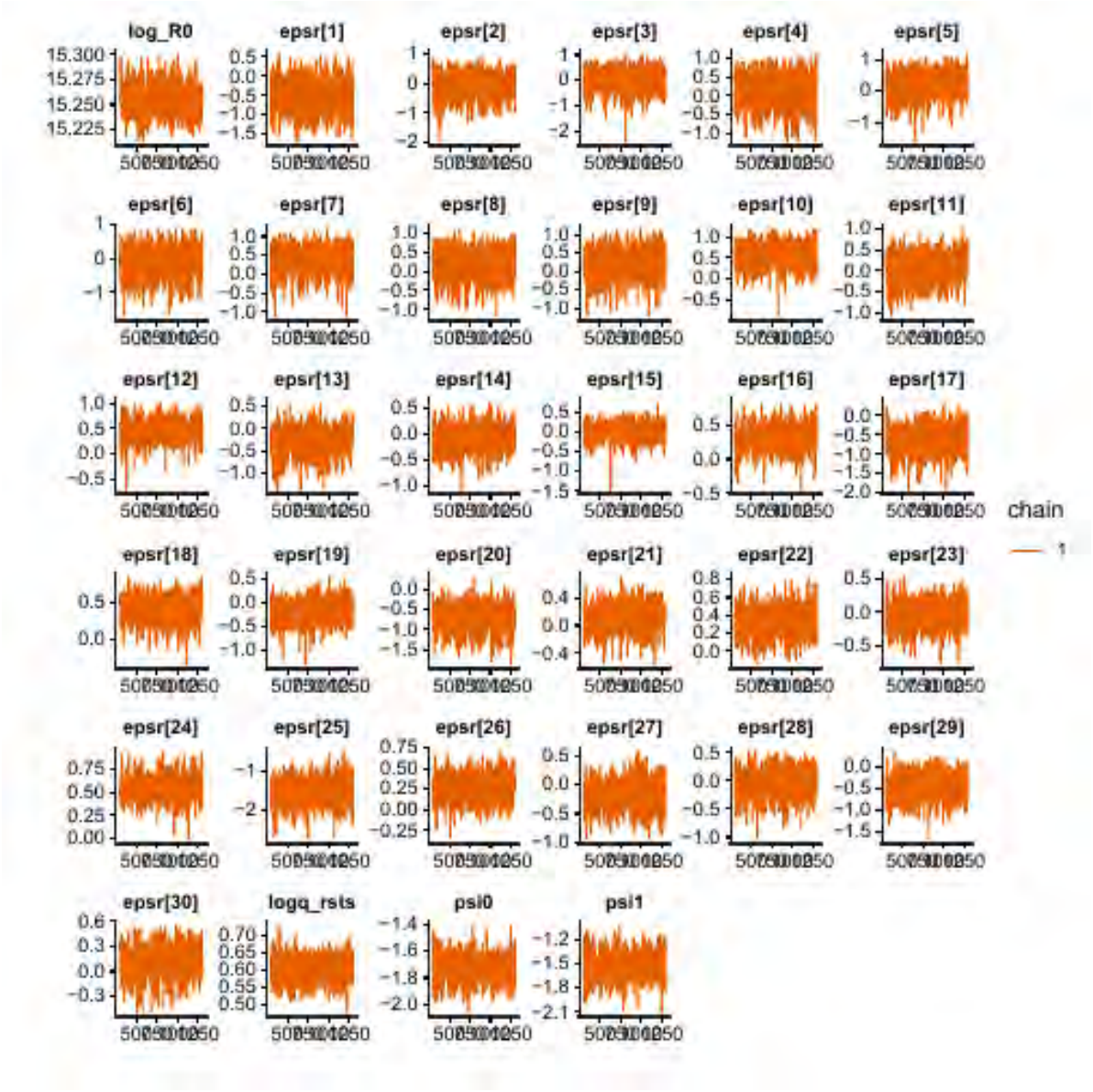


Figure 37: Trace plots for estimated parameters. Only the first chain is shown, however $\hat{R}$ values indicate well mixed chains.

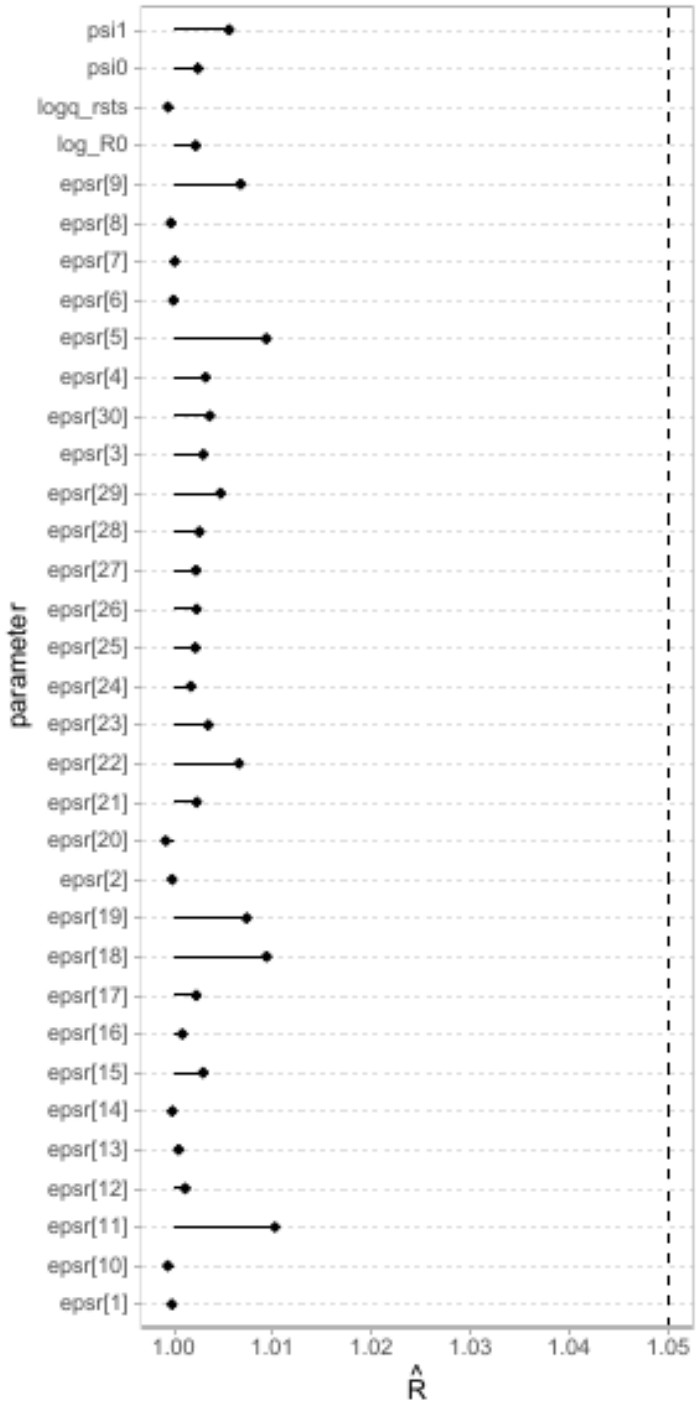


Figure 38: $\hat{R}$ diagnostics for estimated pareameters.

Results and model fits for sensitivity (e) - recruitment deviations estimated to 2019

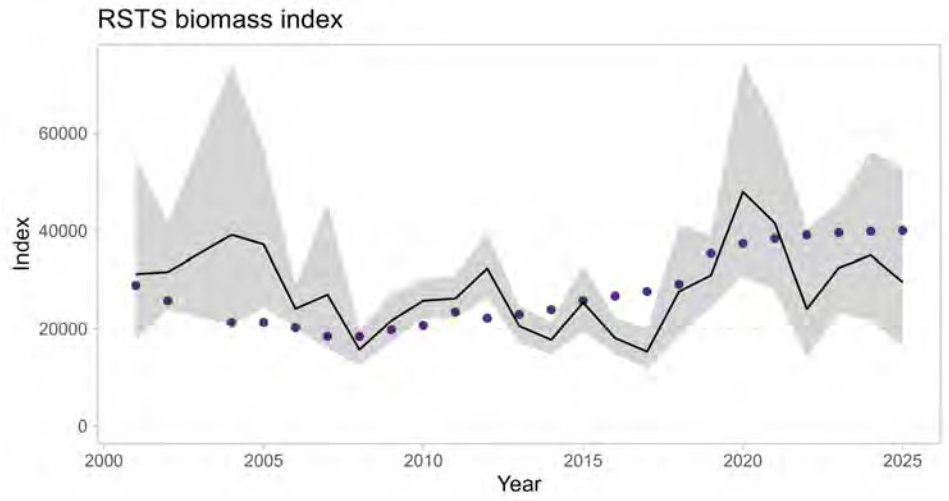


Figure 39: Observed (median and 95$^{\text{th}}$ percentile, line and shaded area) and predicted (circles) RSTS biomass index values for sensitivity run (e).

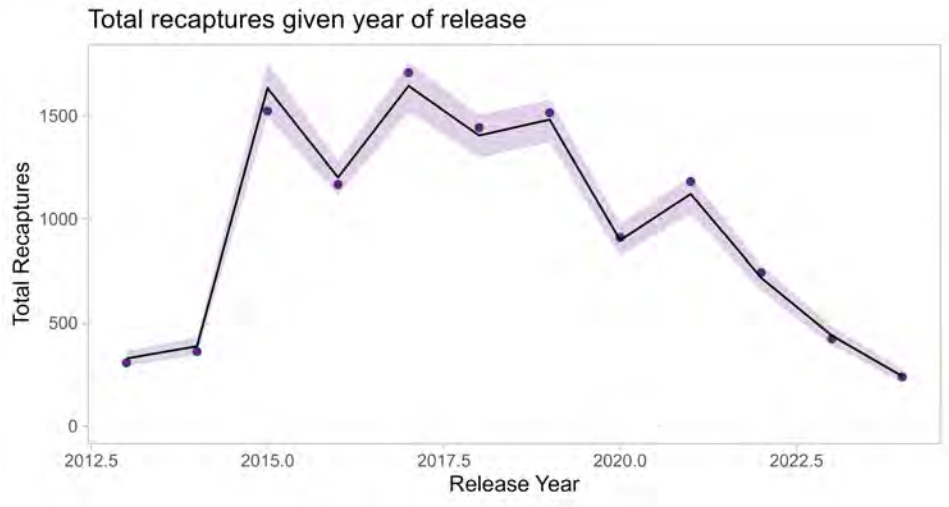


Figure 40: Posterior predictive interval (line and shaded region) and observed (points) overall tag recaptures for each release year on the shelf for sensitivity run (e).

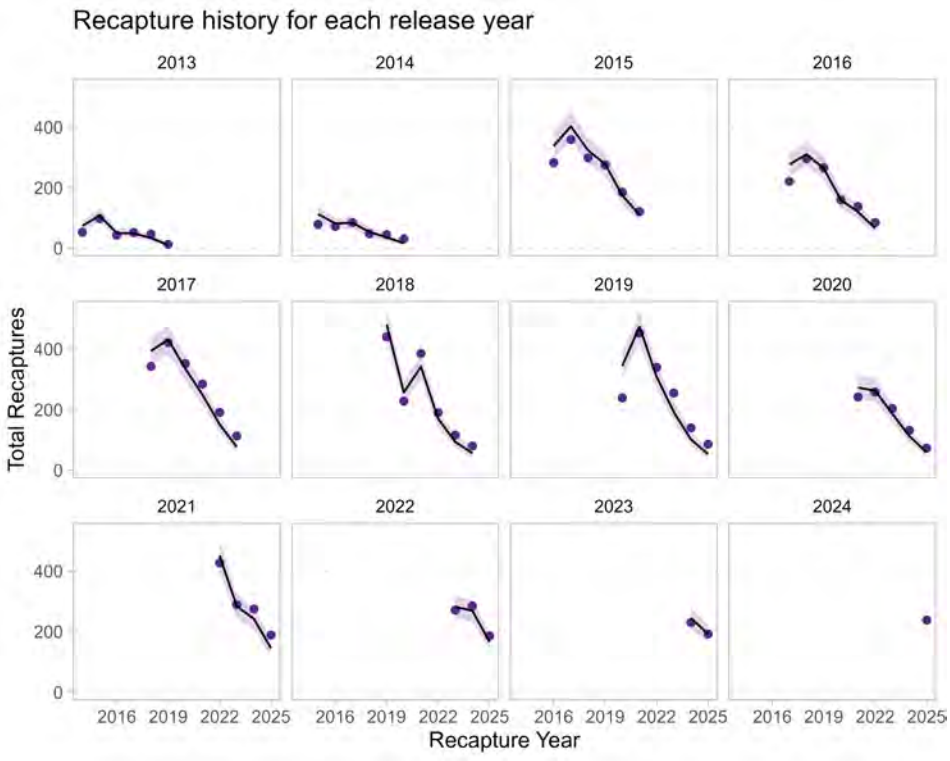


Figure 41: Posterior predictive interval (line and shaded region) and observed (points) tag recaptures for each release year on the shelf for sensitivity run (e).

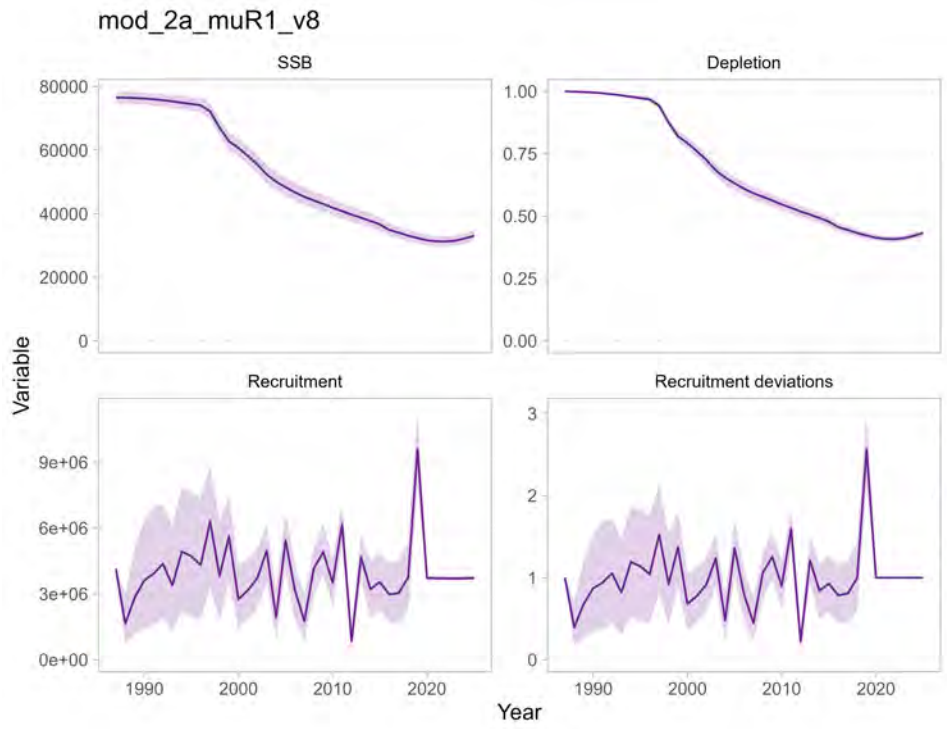


Figure 42: Estimated trajectory of *SSB*, stock status, recruitment and recruitment deviations for sensitivity run (e) showing the median (line) and 95% credible intervals (shaded area).

Results and model fits for sensitivity (f) - including 9 years at liberty for tag data

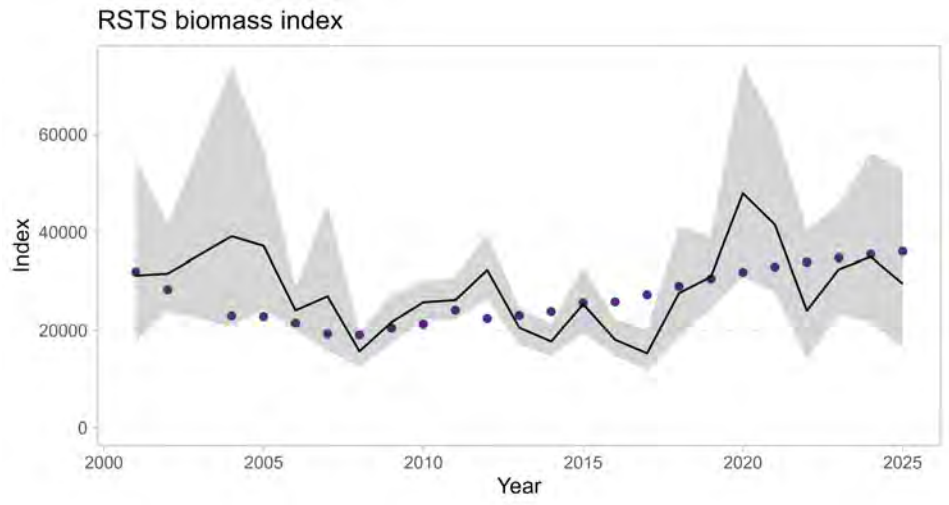


Figure 43: Observed (median and 95$^{\text{th}}$ percentile, line and shaded area) and predicted (circles) RSTS biomass index values for sensitivity run (f).

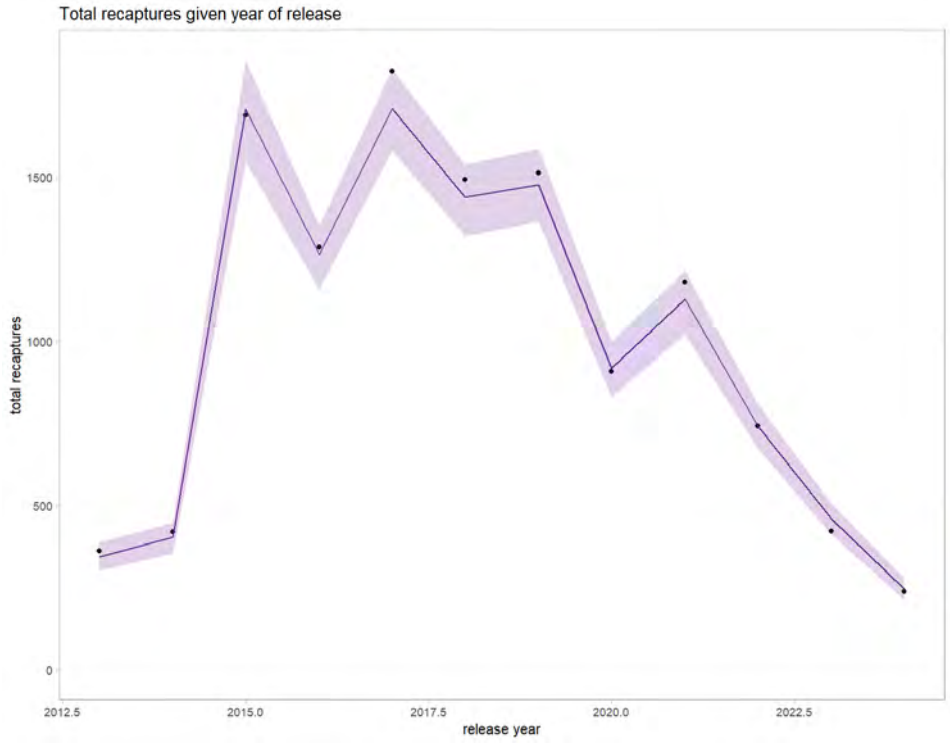


Figure 44: Posterior predictive interval (line and shaded region) and observed (points) overall tag recaptures for each release year on the shelf for sensitivity run (f).

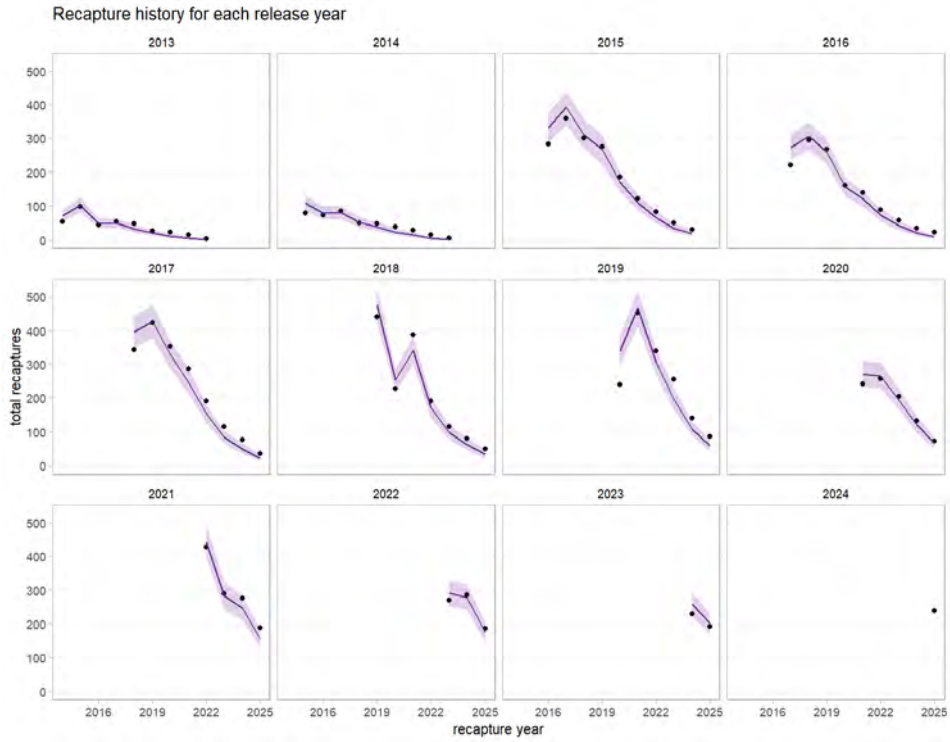


Figure 45: Posterior predictive interval (line and shaded region) and observed (points) tag recaptures for each release year on the shelf for sensitivity run (f).

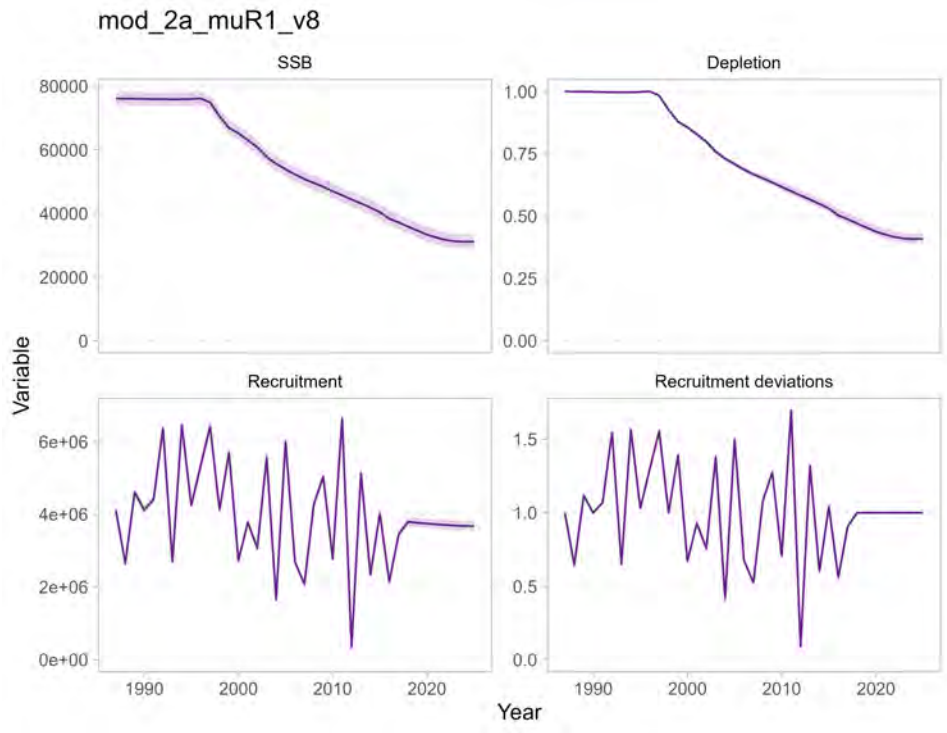


Figure 46: Estimated trajectory of *SSB*, stock status, recruitment and recruitment deviations for sensitivity run (f) showing the median (line) and 95% credible intervals (shaded area).

General summary of responses to climate change indices

Table 13: Heard Island and McDonald Islands Patagonian toothfish (Dissostichus eleginoides) fishery in Division 58.5.2 – General summary of responses to climate change indices

Parameter or process		Effects of environmental variability/change
Recruitment	Mean recruitment	Data from the annual fishery independent survey (RSTS) suggests no change in biomass or age class structure of Patagonian toothfish present in waters surveyed. Inspection of temporal patterns in modelled recruitment suggests a relatively random pattern through time with a small relative decline post 2003.

Parameter or process		Effects of environmental variability/change
	Recruitment variability (σ_R and autocorrelation)	The time series is currently not long enough to evaluate changes in variability, but the depletion rule has not been a constraint in the application of the decision rules in assessments. There is lower certainty in recruitment deviations prior to 2003 however the general magnitude of recruitment deviations is not markedly different through time.
Age at maturity		Sex-specific maturity-at-length was estimated for the first time this year (Bessell-Browne et al. 2026). The use of all length data within these calculations produced a precise estimate that will assist future assessments of trend.
Stock-recruit relationship		The time series of recruitment is not long enough to determine if the stock recruitment relationship is being affected by climate change. Long term monitoring of mean recruitment and its relationship to spawning stock biomass may be able to be used to determine if changes in the relationship occur.
Natural mortality	From direct predation	Not known
	Not from direct predation	Not known
Growth rates		Analysis of length-weight residual patterns across cohorts could be reviewed to consider whether there are any changes in mean size at age.
Lenght-weight		The length-weight relationship was last estimated in 2019 (WG-FSA-19/32). Comparison to earlier estimates (for e.g., 1999) report similar patterns to this estimate.
Sex-ratio changes		Reported annually in RSTS surveys but yet to be investigated in more detail.
Spatial distribution		Noted changes in fishing effort over time as well as some strong concentration of effort in specific years have been examined previously (Masere et al. 2024) yet it is difficult to resolve whether these patterns indicate changes in Patagonian toothfish distribution.

Parameter or process		Effects of environmental variability/change
Stock structure	Revised	There has been no evidence to suggest the stock structure hypothesis for Patagonian toothfish in HIMI has altered from current stock structure hypotheses. However, the the use of a sex-specific, spatial assessment model for the first time this year potentially provides a structure for examining demographic structure in more detail going forward.
	Locations of spawning and site fidelity	Not known
Depredation mortality		To date there has been a relatively small amount of depredation documented at HIMI. Further, it seems to be significantly smaller than in other toothfish fisheries' (Tixier et al. 2019).

References

Bessell-Browne, P., R. M. Hillary, and C. Masere. 2026. Updated biological relationships and tag shedding estimates for the 2026 stock assessment of Patagonian toothfish (Dissostichus eleginoides) in Division 58.5.2. WG-SAM-2026/21. CCAMLR. Masere, C., Le Clech, R., Massiot-Granier, F., Alewijnse, S., Devine, J.A.; Earl, T.; Dunn, A.; Maschette, D.; Ouzoulias, F.; Peron, C.; Readdy, L.; Walker, N.; Ziegler, P. 2024. Consideration of the impact of tagging and recapture effort on mark-recapture abundance estimators within integrated Casal2 stock assessments. WG-SAM-2024/22. CCAMLR, Hobart, Australia. Tixier, P., Burch, P., Richard, G., Olsson, K., Welsford, D., Lea, M-A, Hindell, M. A., Guinet, C., Janc, A., Gasco, N., Duhamel, G., Villanueva, M.C., Suberg, L., Arangio, R., Söfer, M. and Arnould, J.P.Y. 2019. Commercial fishing patterns influence odontocete whale longline interactions in the Southern Ocean. Scientific Reports 9:1904. Yates P., Welsford D., Ziegler P., McIvor J., Farmer B. and E. Woodcock (2017) Spatio-temporal dynamics in maturation and spawning of Patagonian toothfish (Dissostichus eleginoides) on the subantarctic Kerguelen Plateau. Document WG-FSA-17/P04, CCAMLR Hobart, Australia.

Comparison Summary Report

HIMI_TOP_Stock_Assessment.pdf compared with HIMI_TOP_Stock_Assessment_21Sep2026.pdf
2026-10-02 11:51:59
201 changes

Text Changes 201

Insertions	0
Deletions	85
Replacements	116
Moves	0

Visual Changes 0

Insertions	0
Deletions	0
Replacements	0
Moves	0

Formatting Changes 0

Total Changes 201

Revisions Summary Report

HIMI_TOP_Stock_Assessment.pdf compared with HIMI_TOP_Stock_Assessment_21Sep2026.pdf
2026-10-02 11:51:59
201 changes

Added 0 Removed 85 Replaced 116 Moved 0 Formatting 0

#1 (p.1)	Replaced (Text)	**Before:** 30 **After:** 18
#2 (p.1)	Replaced (Text)	**Before:** 12 **After:** 11
#3 (p.1)	Replaced (Text)	**Before:** 12 **After:** 11
#4 (p.2)	Replaced (Text)	**Before:** 19 **After:** 18
#5 (p.2)	Replaced (Text)	**Before:** 22 **After:** 21
#6 (p.2)	Replaced (Text)	**Before:** 39 **After:** 38
#7 (p.2)	Replaced (Text)	**Before:** 40 **After:** 39
#8 (p.2)	Replaced (Text)	**Before:** 41 **After:** 40
#9 (p.2)	Replaced (Text)	**Before:** 42 **After:** 41
#10 (p.2)	Replaced (Text)	**Before:** 45 **After:** 43
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#12 (p.2)	Replaced (Text)	**Before:** 51 **After:** 49
#13 (p.2)	Replaced (Text)	**Before:** 51 **After:** 49
#14 (p.2)	Replaced (Text)	**Before:** 62 **After:** 60
#15 (p.2)	Replaced (Text)	**Before:** 65 **After:** 63
#16 (p.2)	Replaced (Text)	**Before:** 68 **After:** 66
#17 (p.2)	Replaced (Text)	**Before:** 71 **After:** 69

#18 (p.3)	Removed (Text)	This revision includes revised length sample numbers and a model run with revised SIOFA catches, included as sensitivity (k). The length sample numbers were correct in the assessment, where the number of hauls are included as the initial sample size, whereas the number of total number of length measurements taken are presented in this paper, the updated numbers are presented in Table 3. This sensitivity run (k) estimated the same stock status estimate as the reference model presented here with a slightly higher estimate of
#19 (p.3)	Removed (Text)	???
#20 (p.3)	Removed (Text)	0
#21 (p.3)	Removed (Text)	, shown in Table 9 and resulting catch limit, shown in Table 11.
#22 (p.3)	Removed (Text)	3
#23 (p.4)	Removed (Text)	4
#24 (p.5)	Removed (Text)	5
#25 (p.6)	Removed (Text)	6
#26 (p.7)	Removed (Text)	7
#27 (p.8)	Removed (Text)	revised SIOFA catches,
#28 (p.8)	Removed (Text)	c
#29 (p.8)	Removed (Text)	Revised SIOFA catchd
#30 (p.8)	Removed (Text)	0
#31 (p.8)	Removed (Text)	0
#32 (p.8)	Removed (Text)	0
#33 (p.8)	Removed (Text)	0
#34 (p.8)	Removed (Text)	0
#35 (p.8)	Removed (Text)	0
#36 (p.8)	Removed (Text)	0
#37 (p.8)	Removed (Text)	0
#38 (p.8)	Removed (Text)	0
#39 (p.8)	Removed (Text)	0
#40 (p.8)	Removed (Text)	0
#41 (p.8)	Removed (Text)	0
#42 (p.8)	Removed (Text)	0
#43 (p.8)	Removed (Text)	0
#44 (p.8)	Removed (Text)	0
#45 (p.8)	Removed (Text)	0
#46 (p.8)	Removed (Text)	0
#47 (p.8)	Removed (Text)	0

#48 (p.8)	Removed (Text)	0
#49 (p.8)	Removed (Text)	0
#50 (p.8)	Removed (Text)	0
#51 (p.8 → p.7)	Replaced (Text)	**Before:** 2017 3405 20 3 3334 0 3357 27 0 0 0 3380 2018 3525 41 8 3091 0 3140 12 347 339 0 3499 2019 3525 29 38 3333 0 3400 25 169 127 0 3594 2020 3030 84 34 2919 0 3037 30 71 74 0 3135 2021 3030 78 15 2921 4 3018 35 43 38 0 3096 2022 3010 36 30 2709 0 2775 5 29 32 0 2809 2023 3010 67 3 2424 0 2494 0 0 25 0 2494 2024 2660 86 0 2322 0 2408 0 0 28 0 2408 **After:** 7
#52 (p.8)	Removed (Text)	8
#53 (p.9)	Removed (Text)	revised SIOFA catches,
#54 (p.9)	Removed (Text)	c
#55 (p.9)	Removed (Text)	Revised SIOFA catchd
#56 (p.9 → p.8)	Replaced (Text)	**Before:** re-movals 2025 2120 68 9 2040 0 2117 0 **After:** re-movals 2017 3405 20 3 3334 0 3357 27 0 0 3380 2018 3525 41 8 3091 0 3140 12 347c 0 3499 2019 3525 29 38 3333 0 3400 25 169c 0 3594 2020 3030 84 34 2919 0 3037 30 71c 0 3135 2021 3030 78 15 2921 4 3018 35 43 0 3096 2022 3010 36 30 2709 0 2775 5 29 0 2809 2023 3010 67 3 2424 0 2494 0 0 0 2494 2024 2660 86 0 2322 0 2408 0 0 0 2408 2025 2120 68 9 2040 0 2117
#57 (p.9)	Removed (Text)	0
#58 (p.9)	Removed (Text)	d Revised SIOFA catches from SIOFA Secretariat (2026), used in sensitivity run (k).
#59 (p.9)	Removed (Text)	9
#60 (p.10)	Removed (Text)	10
#61 (p.11)	Removed (Text)	-
#62 (p.11)	Removed (Text)	11
#63 (p.12 → p.11)	Replaced (Text)	**Before:** 9229 0 9229 140 **After:** 1129410
#64 (p.12 → p.11)	Replaced (Text)	**Before:** 140 1998 11408 0 1 **After:** 1129410
#65 (p.12)	Removed (Text)	8 181
#66 (p.12 → p.11)	Replaced (Text)	**Before:** 181 **After:** 140
#67 (p.12 → p.11)	Replaced (Text)	**Before:** 9 14650 0 14650 78 0 78 2000 20525 **After:** 8 1596863
#68 (p.12 → p.11)	Replaced (Text)	**Before:** 20525 783 0 783 2001 30108 0 30108 794 **After:** 1596863 181
#69 (p.12 → p.11)	Replaced (Text)	**Before:** 794 2002 21489 0 21489 824 0 824 **After:** 181

#70 (p.12 → p.11)	Replaced (Text)	**Before:** 12 **After:** 11
#71 (p.13 → p.12)	Replaced (Text)	**Before:** 2003 23305 4194 27499 **After:** 1999 964454 0 964454 78 0 78 2000 1109750 0 1109750 783 0 783 2001 1514494 0 1514494 794 0 794 2002 1411056 0 1411056 824 0 824 2003 1679912 167733 1847645
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#73 (p.13 → p.12)	Replaced (Text)	**Before:** 19412 13138 32550 **After:** 785823 695011 1480834
#74 (p.13 → p.12)	Replaced (Text)	**Before:** 17315 16220 33535 **After:** 651020 351281 1002301
#75 (p.13 → p.12)	Replaced (Text)	**Before:** 16151 8785 24936 **After:** 666170 390149 1056319
#76 (p.13 → p.12)	Replaced (Text)	**Before:** 16331 16600 32931 **After:** 559915 893811 1453726
#77 (p.13 → p.12)	Replaced (Text)	**Before:** 15151 31281 46432 **After:** 559773 1840931 2400704
#78 (p.13 → p.12)	Replaced (Text)	**Before:** 20268 18466 38734 **After:** 1453649 1227685 2681334
#79 (p.13 → p.12)	Replaced (Text)	**Before:** 13211 24941 38152 **After:** 860508 1496686 2357194
#80 (p.13 → p.12)	Replaced (Text)	**Before:** 23159 20065 43224 **After:** 3118282 1149556 4267838
#81 (p.13 → p.12)	Replaced (Text)	**Before:** 9751 35897 45648 **After:** 445628 1646210 2091838
#82 (p.13 → p.12)	Replaced (Text)	**Before:** 2770 42791 45561 **After:** 47788 2739183 2786971
#83 (p.13 → p.12)	Replaced (Text)	**Before:** 6074 71534 77608 **After:** 320950 4580308 4901258
#84 (p.13 → p.12)	Replaced (Text)	**Before:** 5630 51441 57071 **After:** 585878 2039162 2625040
#85 (p.13 → p.12)	Replaced (Text)	**Before:** 2592 64789 67381 **After:** 357762 2487087 2844849
#86 (p.13 → p.12)	Replaced (Text)	**Before:** 3787 58553 62340 **After:** 1241474 1858376 3099850
#87 (p.13 → p.12)	Replaced (Text)	**Before:** 3904 61196 65100 **After:** 712642 2061750 2774392
#88 (p.13 → p.12)	Replaced (Text)	**Before:** 4738 25316 30054 **After:** 4476791 1313423 5790214
#89 (p.13 → p.12)	Replaced (Text)	**Before:** 4455 39662 44117 **After:** 2755789 2053672 4809461

#90 (p.13 → p.12)	Replaced (Text)	**Before:** 3239 47205 50444 **After:** 1927821 2045075 3972896
#91 (p.13 → p.12)	Replaced (Text)	**Before:** 3636 36036 39672 **After:** 1792280 1882658 3674938
#92 (p.13 → p.12)	Replaced (Text)	**Before:** 2684 36627 39311 **After:** 2512860 1875390 4388250
#93 (p.13 → p.12)	Replaced (Text)	**Before:** 4124 28267 32391 **After:** 360518 1568991 1929509
#94 (p.13 → p.12)	Replaced (Text)	**Before:** 13 **After:** 12
#95 (p.14 → p.13)	Replaced (Text)	**Before:** 14 **After:** 13
#96 (p.15 → p.14)	Replaced (Text)	**Before:** 15 **After:** 14
#97 (p.16 → p.15)	Replaced (Text)	**Before:** 16 **After:** 15
#98 (p.17 → p.16)	Replaced (Text)	**Before:** 17 **After:** 16
#99 (p.18)	Removed (Text)	-
#100 (p.18 → p.17)	Replaced (Text)	**Before:** 18 **After:** 17
#101 (p.19 → p.18)	Replaced (Text)	**Before:** 19 **After:** 18
#102 (p.20 → p.19)	Replaced (Text)	**Before:** 20 **After:** 19
#103 (p.21 → p.20)	Replaced (Text)	**Before:** 21 **After:** 20
#104 (p.22 → p.21)	Replaced (Text)	**Before:** 22 **After:** 21
#105 (p.23 → p.22)	Replaced (Text)	**Before:** 23 **After:** 22
#106 (p.24 → p.23)	Replaced (Text)	**Before:** splits based on t **After:** of 20 tonnes. T
#107 (p.24 → p.23)	Replaced (Text)	**Before:** average proportion of **After:** entire remaining future
#108 (p.24 → p.23)	Replaced (Text)	**Before:** each fishery over **After:** longline, with a catch split based on the overall catch distribution of longline sub-fisheries in
#109 (p.24 → p.23)	Replaced (Text)	**Before:** four **After:** three
#110 (p.24 → p.23)	Replaced (Text)	**Before:** before projections commence. **After:** , i.e. 60% of the total catch was attributed to LL1 selectivity and 40% of the total catch was attributed to LL2 selectivity.

#111 (p.24 → p.23)	Replaced (Text)	**Before:** 24 **After:** 23
#112 (p.25)	Removed (Text)	Total 8616.80
#113 (p.25 → p.24)	Replaced (Text)	**Before:** 25 **After:** 24
#114 (p.26)	Removed (Text)	vi
#115 (p.26 → p.25)	Replaced (Text)	**Before:** Figure 36 **After:** (?)
#116 (p.26 → p.25)	Replaced (Text)	**Before:** 26 **After:** 25
#117 (p.27 → p.26)	Replaced (Text)	**Before:** 27 **After:** 26
#118 (p.28 → p.27)	Replaced (Text)	**Before:** 28 **After:** 27
#119 (p.29 → p.28)	Replaced (Text)	**Before:** 29 **After:** 28
#120 (p.30 → p.29)	Replaced (Text)	**Before:** 30 **After:** 29
#121 (p.31 → p.30)	Replaced (Text)	**Before:** 31 **After:** 30
#122 (p.32 → p.31)	Replaced (Text)	**Before:** 32 **After:** 31
#123 (p.33 → p.32)	Replaced (Text)	**Before:** 33 **After:** 32
#124 (p.34 → p.33)	Replaced (Text)	**Before:** 34 **After:** 33
#125 (p.35)	Removed (Text)	Run (k) includes the revised SIOFA catches which were incorrect in the original assessment and model runs.
#126 (p.35 → p.34)	Replaced (Text)	**Before:** . • For the run with amended SIOFA catches, estimates of stock status were the same as the reference model, with very small increases in estimates of **After:** .
#127 (p.35)	Removed (Text)	???
#128 (p.35)	Removed (Text)	0
#129 (p.35)	Removed (Text)	and
#130 (p.35)	Removed (Text)	?
#131 (p.35)	Removed (Text)	0
#132 (p.35)	Removed (Text)	.
#133 (p.35)	Removed (Text)	35
#134 (p.36)	Removed (Text)	Table 9: MPD results of reference model and sensitivity analyses, with estimates of unfished spawning stock biomass SSB0

#135 (p.36)	Removed (Text)	in tonnes, SSB status at the end of 2026, R0
#136 (p.36)	Removed (Text)	(mean recruitment in millions that gives rise to SSB0
#137 (p.36)	Removed (Text)	), survey catchability q, and the number of estimated parameters (N Parameters). Sensitivity run SSB0
#138 (p.36)	Removed (Text)	SSB status R0
#139 (p.36)	Removed (Text)	Survey q N Parameters
#140 (p.36)	Removed (Text)	k) revised SIOFA catches 78387 0.42 4.25 1.82 131
#141 (p.36 → p.34)	Replaced (Text)	**Before:** Figure 42 **After:** (?)
#142 (p.36 → p.34)	Replaced (Text)	**Before:** Figure 46 **After:**
#143 (p.36 → p.35)	Replaced (Text)	**Before:** 36 **After:** 35
#144 (p.37 → p.36)	Replaced (Text)	**Before:** 37 **After:** 36
#145 (p.38 → p.37)	Replaced (Text)	**Before:** 38 **After:** 37
#146 (p.39)	Removed (Text)	-
#147 (p.39)	Removed (Text)	-
#148 (p.39 → p.38)	Replaced (Text)	**Before:** 39 **After:** 38
#149 (p.40 → p.39)	Replaced (Text)	**Before:** 40 **After:** 39
#150 (p.41 → p.40)	Replaced (Text)	**Before:** 41 **After:** 40
#151 (p.42)	Removed (Text)	and senstivity run (k) where the revised SIOFA catches were included
#152 (p.42 → p.41)	Replaced (Text)	**Before:** Table 11 also demonstrates the marginally higher catch limit estimated when including the revised SIOFA catches in the assessment. **After:**
#153 (p.42 → p.41)	Replaced (Text)	**Before:** 42 **After:** 41
#154 (p.43 → p.42)	Replaced (Text)	**Before:** lt **After:** tl
#155 (p.43 → p.42)	Replaced (Text)	**Before:** , **After:** and
#156 (p.43)	Removed (Text)	and sensitivity run (k) with revised SIOFA catches.
#157 (p.43)	Removed (Text)	Sensitivity (k) 1988-2017 3544 0.5 <0.01
#158 (p.43)	Removed (Text)	43
#159 (p.44)	Removed (Text)	44

#160 (p.45)	Removed (Text)	-
#161 (p.45)	Removed (Text)	-
#162 (p.45)	Removed (Text)	45
#163 (p.46)	Removed (Text)	46
#164 (p.47)	Removed (Text)	47
#165 (p.48)	Removed (Text)	48
#166 (p.49 → p.48)	Replaced (Text)	**Before:** vi- **After:** -vi
#167 (p.49)	Removed (Text)	49
#168 (p.50)	Removed (Text)	50
#169 (p.51)	Removed (Text)	SIOFA Secretariat. 2026. SIOFA Fisheries Summary: toothfish (Dissostichus eleginoides, Dis-sostichus mawsoni, Dissostichus spp.) 2026. Southern Indian Ocean Fisheries Agreement (SIOFA).
#170 (p.51)	Removed (Text)	-
#171 (p.51)	Removed (Text)	51
#172 (p.52 → p.50)	Replaced (Text)	**Before:** 52 **After:** 50
#173 (p.53 → p.51)	Replaced (Text)	**Before:** 53 **After:** 51
#174 (p.54 → p.52)	Replaced (Text)	**Before:** 54 **After:** 52
#175 (p.55 → p.53)	Replaced (Text)	**Before:** 55 **After:** 53
#176 (p.56 → p.54)	Replaced (Text)	**Before:** 56 **After:** 54
#177 (p.57 → p.55)	Replaced (Text)	**Before:** 57 **After:** 55
#178 (p.58 → p.56)	Replaced (Text)	**Before:** 58 **After:** 56
#179 (p.59 → p.57)	Replaced (Text)	**Before:** 59 **After:** 57
#180 (p.60 → p.58)	Replaced (Text)	**Before:** 60 **After:** 58
#181 (p.61 → p.59)	Replaced (Text)	**Before:** 61 **After:** 59
#182 (p.62 → p.60)	Replaced (Text)	**Before:** 62 **After:** 60
#183 (p.63 → p.61)	Replaced (Text)	**Before:** 63 **After:** 61
#184 (p.64)	Removed (Text)	for

#185 (p.64)	Removed (Text)	All
#186 (p.64)	Removed (Text)	?
#187 (p.64 → p.62)	Replaced (Text)	**Before:** ? **After:** ?
#188 (p.64)	Removed (Text)	) were greater than 400.
#189 (p.64)	Removed (Text)	?
#190 (p.64 → p.62)	Replaced (Text)	**Before:** 64 **After:** for
#191 (p.65 → p.63)	Replaced (Text)	**Before:** 65 **After:** 63
#192 (p.66 → p.64)	Replaced (Text)	**Before:** 66 **After:** 64
#193 (p.67 → p.65)	Replaced (Text)	**Before:** 67 **After:** 65
#194 (p.68 → p.66)	Replaced (Text)	**Before:** 68 **After:** 66
#195 (p.69 → p.67)	Replaced (Text)	**Before:** 69 **After:** 67
#196 (p.70 → p.68)	Replaced (Text)	**Before:** 70 **After:** 68
#197 (p.71 → p.69)	Replaced (Text)	**Before:** 71 **After:** 69
#198 (p.72 → p.70)	Replaced (Text)	**Before:** 72 **After:** 70
#199 (p.73 → p.71)	Replaced (Text)	**Before:** 73 **After:** 71
#200 (p.74 → p.72)	Replaced (Text)	**Before:** 74 **After:** 72
#201 (p.75 → p.73)	Replaced (Text)	**Before:** 75 **After:** 73