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Silver Warehou (*Seriolella punctata*) stock assessment based on data up to 2017

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Revised after the SERAG meeting 14-16 November 2018, Hobart, Tasmania.

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Executive summary

This document presents a quantitative Tier 1 assessment of silver warehou (*Seriolella punctata*) in the Southern and Eastern Scalefish and Shark Fishery (SESSF) using data up to 31 December 2017. The last full assessment was presented in Day *et al.* (2015). The 2018 assessment has been updated by the inclusion of data up to the end of 2017, which entails an additional three years of catch, discard, CPUE, length-composition and conditional age-at-length data and ageing error updates. This document describes the 2018 assessment for silver warehou through the sequential updating of recent data to the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30.12).

Silver warehou catches peaked at 4,100t in 2002 and subsequently declined to less than 2,000t from 2007 onwards, with further declines to less than 1,000t since 2012. Since 2014 catches have remained relatively stable since 2014 at between 350t and 400t. Over the last decade catches have remained substantially lower than the agreed total allowable catch (TAC).

The preliminary base case was presented to the September 2018 meeting of the South and East Resource Assessment Group (SERAG; Burch *et al.* 2018). SERAG discussed the validity of the catch and discard data and requested that the fishery independent survey (FIS) be removed from the base case and the 2015 recruitment not be estimated. Following the meeting an investigation of the catch and discard data led to a number of changes to the 2018 base case that were communicated to AFMA and the SERAG chair in October. These changes were: the use of a re-estimated discard fractions split between the eastern and western trawl fleets, accounting for the observed discarding practices of factory trawlers, the inclusion of conditional age-at-length data for the western onboard trawl fleet, removal of length data from the small pelagic fishery (SPF) and inclusion of non-trawl catches in the existing eastern and western trawl fleets.

Results show reasonable fits to the CPUE abundance index for the western trawl fleet, however, fits to the eastern trawl fleet are poor prior to 2008. There are differences in the length distributions from onboard and port sampling in both the east and the west, resulting in poor fits to the aggregated length distributions for the eastern trawl fleet. In the west, the fits to the aggregated length distributions were reasonable. The overall fits to the retained length and conditional age-at-length data are reasonable, although there are poor fits in some years. Fits to the discard length data are poor, particularly in the west.

This assessment has seen a continuation of below average recruitment noted in the last two assessments (Day *et al.* 2012, 2015) with the last 11 years of estimated recruitment all below average. While the current assessment estimates that spawning biomass in 2019 will be 31% of unfished levels, previous assessments (Day *et al.* 2012, 2015) have shown that optimistic recent recruitments have been revised downwards in subsequent assessments. This may indicate that a regime shift has occurred for this stock.

Given the changes to the assessment structure, data and tuning methods since the 2012 assessment, a retrospective analysis was undertaken to determine whether the pattern of optimistic recent recruitments have been revised downwards in subsequent assessments was still present with the 2018 assessment structure. Increases in recruitment and spawning biomass in the most recent years from the 2014 and 2016 assessment scenarios that were revised downwards in subsequent assessments. This suggests that the increase in spawning biomass seen in the most recent years of the 2018 assessment may be overly optimistic and that the stock may currently be near the limit reference point.

This assessment estimates that the projected 2019 spawning stock biomass will be 31.3% of virgin stock biomass. The recommended biological catch (RBC) from the base case model for 2019 is 942t for the 20:35:48 harvest control rule, increasing to 1,353t in 2020 and 1,420t in 2021. The long-term yield is 1,772t. In comparison, the 2015 assessment estimated the 2016 spawning biomass to be 40% of the unfished level, with corresponding RBCs of 1,958t, with a long-term yield of 2,281t. However, these scenarios assume recruitment will return to average levels. Low and very low recruitment scenarios suggest that if current landed catches are maintained at around 350t per annum then the stock is likely to remain above the limit reference point.

A Bayesian assessment was undertaken because the base case assessment showed that the maximum likelihood estimate of spawning biomass was near the limit reference point of 20% of its unfished level between 2013 and 2016. The Bayesian assessment estimated the probability that the spawning biomass was below the limit reference point was greater than 20% between 2013 and 2016. In 2017 the probability the spawning biomass was below the limit reference point was 8% and in 2018 and 2019 the probability the spawning biomass was below the limit reference point is <1%.

At its November 2018 meeting, SERAG agreed to recommend a TAC for silver warehou based on the assumption that recruitment will remain below average in the next few years. SERAG chose to assume that recruitment would remain at the mean of the last five years of estimated recruitments in the base case model (2010 – 2014). Projections assuming this low recruitment were run for scenarios of constant landed catch that were between the catch in the most recent year for which data is available (348 t) and the RBCs from the base case model which assumes average recruitment (942 t in 2019). Scenarios with constant annual catches of 750 t or more led to the estimated spawning biomass declining under the low recruitment scenario. Under the low recruitment scenario with constant annual catches between 348 t and 600 t, spawning biomass is predicted to increase, albeit more slowly than the base case which assumes average recruitment.

1 Introduction

1.1 The Fishery

Silver warehou occur throughout the SESSF in depths to 600m and are predominantly caught by demersal trawl (Morison *et al.*, 2007, Sporcic *et al.* 2015, Thomson *et al*. 2015). Silver warehou have also been captured off western Tasmania as bycatch of the winter spawning blue grenadier fishery. In addition to demersal trawl, there have also been some gillnet catches (Morison *et al.*, 2007) and catches by the small pelagic fishery (SPF) using mid-water trawl. Annual catches (landings by fleet) of silver warehou by calendar year are shown in Table 2.

Large catches of silver warehou were first taken in the 1970's (Smith, 1994) and landed catches increased to around 2,000t in the early 1990s and peaked at 4,100t in 2002 (Table 2, Figures 2, 3). Catches declined to less than 2,000t from 2007 onwards, with further declines to less than 1,000t since 2012. Catches have remained relatively stable since 2014 at between 350t and 400t. Catches are described in more detail in Section 2.1.3.

For 2016, 2017 and 2018 the agreed total allowable catches (TACs) were 1,209t, 605t and 600t respectively. These TACs were set following the last assessment in 2015 (Day *et al.*, 2015) assuming a low recruitment scenario.

1.2 Stock Structure

Prior to 2015 silver warehou was assessed as a single population using a single trawl fleet in SESSF zone 10 – 50 (Day *et al.* 2012; Figure 1). However, differences in standardised catch rates, length and age distribution east and west of longitude 147° E were identified by Sporcic *et al.* (2015). This led to the development of a preliminary assessment which split the data into two fleets, an eastern fleet (SESSF zones 10, 20 and 30) and a western fleet (SESSF zones 40 and 50; Thomson *et al.* 2015). This fleet structure was adopted as the base case for the 2015 assessment (Day et al. 2015) and has been retained as the base case for the 2018 silver warehou assessment (Burch *et al.* 2018).

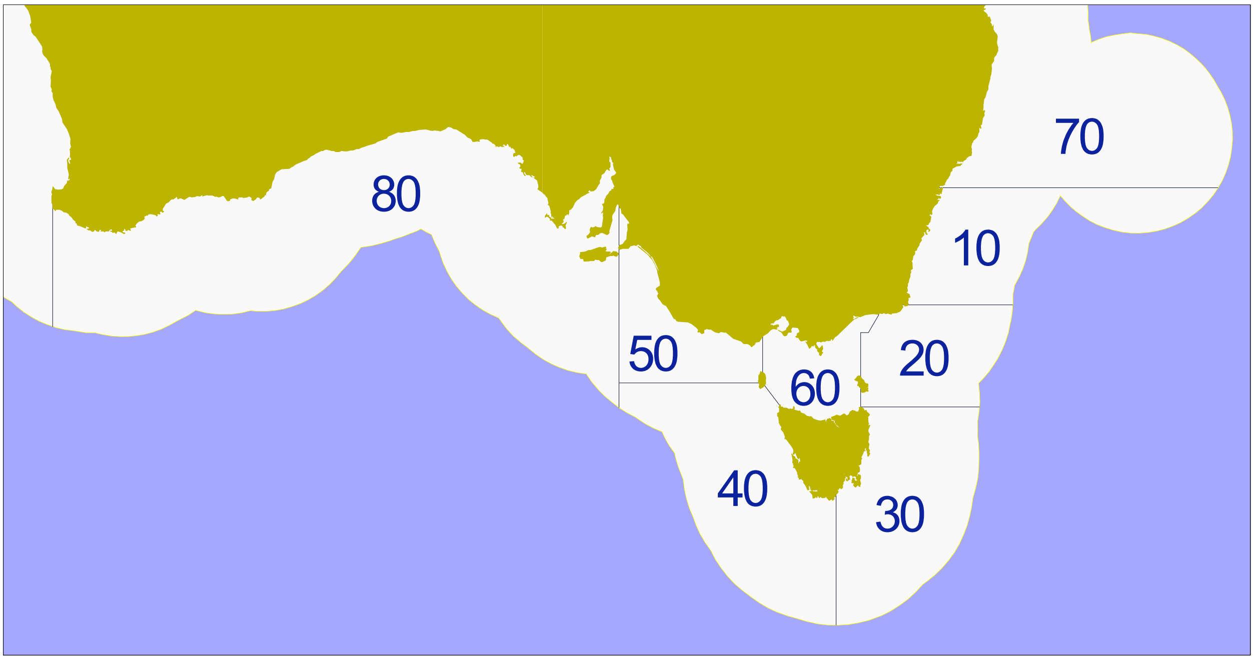


Figure 1. Map of the SESSF showing statistical zones.

1.3 Previous Assessments

The previous full quantitative assessment for silver warehou was performed in 2015 (Day *et al.*, 2015) using Stock Synthesis (SS-V3.24U, Methot 2015). The 2015 assessment indicated that the spawning stock biomass levels in 2016 were around 40% of virgin biomass, however, recruitment for nine out of the ten most recent years was estimated to be below average and the TACs for 2016 – 2018 were set assuming below average future recruitment.

The 2012 assessment (Day *et al.* 2012) modelled the stock using a single trawl fleet in SESSF zones 10 – 50, which continued the fleet structure from previous assessments (e.g. Tuck and Fay 2009). Prior to the 2015 assessment identification of heterogeneity in standardised catch per unit effort (CPUE) between the eastern (SESSF zones 10 – 30) and the western (SESSF zones 40 – 50) areas (Sporcic *et al.* 2015) prompted a re-examination of the fleet structure in the assessment. Thomson *et al.* (2015) investigated the relationship between depth and silver warehou length frequency. They concluded there was a strong relationship between length frequencies of fish caught in the west and those caught in deeper water, and a similar relationship between those caught in the east and in shallow waters, with larger fish generally caught in the west and in deeper water. This led to the development of a preliminary base case assessment which split the single trawl fleet into eastern (SESSF zones 10-30) and western (SESSF zones 40-50) fleets (Thomson *et al*. 2015). Thomson *et al.* (2015) also identified evidence of changing discarding practices within the fishery with both size and market based discarding occurring up until 2001 and only size based discarding from 2002 onwards. This permitted discard rates to be estimated within the 2015 assessment using separate retention functions pre and post 2002 (Day *et al.* 2015). The changes to the fleet structure and how discards are accounted for led to improvements in the fits to the length and age composition data compared with previous assessments (e.g. Day *et al.* 2012, Tuck and Fay 2009).

Prior to 2012, an assessment for silver warehou was performed in 2009 (Tuck and Fay, 2009) using Stock Synthesis (version SS-V3.03a, Methot, 2009) and this assessment indicated that the spawning stock biomass levels in 2010 were around 48% of virgin biomass. Fits to the length, age, and catch-rate data were reasonable. The fit to the catch rate index was a substantial improvement compared to Tuck and Punt, (2007), with changes to the estimates of mortality and growth. Exploration of model sensitivity showed that the model outputs are sensitive to the value assumed for natural mortality, *M*.

Before the 2009 assessment, other Stock Synthesis based assessments for silver warehou were performed in: 2008 (Tuck, 2008) with a spawning biomass estimate for 2007/8 of 53% of the unfished level; 2007 (Tuck and Punt, 2007) with a spawning biomass estimate for 2007/8 of 49% of unfished levels. Even earlier assessments include Taylor and Smith, (2004) and Thomson, (2002).

1.4 Modifications to the 2015 assessment

The 2015 assessment made two substantial changes to structure of the silver warehou assessment, splitting a single trawl fleet into eastern and western fleets and estimating discarded catches within the assessment (Day *et al.* 2015). Both of these changes have been retained and we have made the following changes to the 2015 assessment:

1. CPUE, Catch, discard, length frequency, and age at length data for 2015, 2016 and 2017 have been added.
2. Catches from the Gillnet, Hook and Trap sector (GHAT) and the SPF are now included in the assessment.
3. Recruitment is estimated until 2014 (two more years than the last assessment).
4. The ageing error matrix has been updated.
5. Estimated annual discard rates that are fitted to by the assessment have been split into eastern and western components.
6. Discard estimates have been updated in 2018 to more closely match the discard calculations in Bergh et al. (2009). These estimates use ratios of total discards to (retained + discard) catch on a per shot basis, rather than aggregated across a whole strata, which are then weighted up according to CDR landings within zone and season (N. Klaer, pers. comm.).
7. Factory trawlers are now included in the estimation of annual discard rates when there is observer coverage.
8. The retention function remains time blocked with the second period extended to 2017, reflecting changes in the discarding practices in the periods 1980-2001 and 2002-2017.
9. FIS abundance indices for east and west fleets are removed from the base case assessment and are instead considered as a sensitivity.
10. A new tuning procedure has been used to balance the weighting of each of the data sources that contribute to the overall likelihood function.

These changes and their impact on the assessment are described in detail in Burch et al (2018) and Section 2.1.

1.5 The data and model input

1.5.1 Biological parameters

A single sex model (i.e. both sexes combined) was used, as the length composition data for silver warehou are not available by sex. A summary of the key biological parameters, including the values of the fixed parameters in the base case model is provided in Table 1.

Growth was assumed to follow the von Bertalanffy growth model with parameters estimated within the model-fitting procedure because Stock Synthesis accepts age-at-length data as an input. Estimating the parameters of the von Bertalanffy growth curve within the assessment is more appropriate because it better accounts for the impact of gear selectivity on the age-at-length data collected from the fishery and the impact of ageing error.

This assessment follows that of Day *et al*. (2012, 2015) and Tuck and Fay (2009) in using the base-case value of natural mortality of M=0.3yr^{-1}. Likelihood profiles of natural mortality undertaken for the preliminary base case (Burch *et al.* 2018) and presented to the September 2018 SERAG meeting suggested a value of natural mortality of M=0.5yr^{-1} was preferred by the model. As such a high value of natural mortality is inconsistent with the biology of the species, natural mortality was retained at a fixed value of M=0.3yr^{-1}. The base case value of the steepness of the stock-recruitment relationship, h, is 0.75 Sensitivities to this value for M and h are considered.

Silver warehou become sexually mature at a length of about 37 cm. Fecundity is assumed to be proportional to spawning biomass. The parameters of the length-weight relationship are the same as those used in previous assessments (a=6.5 x 10^{-6}, b=3.27). These values come from Taylor and Smith (2004) and were provided by David Smith (unpublished data).

Table 1. Summary of fixed and estimated parameters for the base case assessment.

Parameter	Details		
Natural mortality (M)	fixed	0.3	
Steepness (h)	fixed	0.75	
length-weight scale, a	fixed	6.50E-06	
length-weight power, b	fixed	3.27	
length at 50% maturity (cm)	fixed	37	
maturity slope	fixed	-6	
Recruitment deviations	estimated	1980-2014	
CV growth	estimated	0.0808	
Growth K	estimated	Female 0.312	
Growth l_{min}	estimated	Female age 2	14.82
Growth l_{max}	estimated	Female	51.21
length at 50% selectivity (cm)	estimated	22.82 (east)	39.87 (west)
selectivity spread (cm)	estimated	3.48 (east)	11.24 (west)
ln(R_0)	estimated	9.379	

1.5.2 Fleets

The base case assessment for silver warehou is based on a trawl fleet split into and eastern trawl fleet (SESSSF zones 10, 20 and 30) and a western trawl fleet (SESSF zones 40 and 50), with time-invariant logistic selectivity estimated separately for each fleet. Prior to the 2015 assessment, discards were added to the landed catch due to difficulties in distinguishing between sized based discarding and market based discarding. This assumption ignored the size-related discarding of small fish that was occurring along with market related discarding of fish of all sizes, as evidenced by the greater proportion of small fish in the discarded length frequencies from 2002 onwards relative to the retained LFs from 2002 onwards (Thomson *et al.* 2015). The 2015 assessment incorporated separate retention (discard) functions which were estimated for the 1980-2001 and 2002-2014 periods. This enabled a retention function to be fitted allowing for this apparent change in discarding practice from 2002 onwards and also resulted in improvements to the fits to the length residuals (Day *et al.* 2015).

Previous assessments excluded non-trawl catches because they were small and the assessments were insensitive to their inclusion (e.g. Thomson 2002). This assessment now includes non-trawl catches assigned to the eastern and western trawl fleets based on the location of the catches. This change was made because of increasing catches of silver warehou from the SPF in 2015 and 2016 and is described in more detail in Section 2.1.3.

1.5.3 Catches

The model uses a calendar year for all catch data. The catch history of silver warehou from 1994 onwards has been revised in the 2018 assessment to account for updates to the database made by AFMA (Thomson *et al.* 2018) and given by Castillo-Jordán *et al.* (2018).

The first model year is 1980, however, SEF1 record-keeping did not begin until 1985. Landings of silver warehou prior to 1985 are not considered to have been large and a linear increase in catch from 1980 to 1985 was assumed, following Punt *et al.* (2005). Silver warehou are closely related to blue warehou and historically catches have often been reported mixed, or with all warehou species combined and referred to as Tassie trevally (Sporcic *et al.* 2015). This practice was most prevalent in the late 1980s with it unclear which species was caught and recorded in Commonwealth logbooks. For this reason, catches prior to 1994 have not been revised and are instead taken from Table 11 of Sporcic *et al*. (2015) and shown in the first column of Table 2. These catches differ slightly from those in the 2015 assessment because of an error in removing discards from the total catch (discarded and retained) when discarded catches were first estimated in the silver warehou assessment.

Previous assessments have excluded non-trawl catches as they were small and the assessment was insensitive to their inclusion. While the majority of the catch is still taken by demersal trawl, in 2015 and 2016 catches of silver warehou of 28t and 50t respectively were recorded by the SPF. While these catches were small compared to catches in the 1990s and early 2000s (Table 2, Figures 2, 3) with the decline in landings they constitute 7% and 14% of the silver warehou catches in 2015 and 2016 respectively. Catch disposal records (CDR) from the SPF, along with those from the Gillnet, Hook and Trap sector (GHAT) are combined with those from demersal trawling (Commonwealth Trawl Sector; CTS) to obtain total landed catches used in the assessment (Table 2). These catches were then split into eastern and western trawl fleets for the assessment based on the proportion of logbook catch east and west of 147° longitude (Table 2, Figures 2, 3). Prior to 1985, it was assumed 50% of the catch was taken east of 147° longitude and 50% was taken west of 147° longitude.

Table 2. Catch from the 2015 stock assessment (Day *et al.* 2015) with discards removed, catches by the Commonwealth Trawl Sector (CTS) the gillnet, hook and trap (GHAT) and small pelagic fishery (SPF). The total landed catch used in the 2018 assessment, the 2018 catch split into the eastern and western trawl fleets and the agreed TACs for silver warehou. Shaded columns represent catches used in the 2018 base case assessment. Grey cells denote the total landings used in the 2018 assessment.

	2015	2018 Catch (t) by Sector			2018 Assessment Catch (t)			
Year	Catch (t)	CTS	GHAT	SPF	Total	East trawl	West trawl	TAC
1980	59.0	-	-	-	59.0	29.5	29.5	-
1981	118.1	-	-	-	118.1	59.0	59.0	-
1982	177.1	-	-	-	177.1	88.6	88.6	-
1983	236.2	-	-	-	236.2	118.1	118.1	-
1984	295.2	-	-	-	295.2	147.6	147.6	-
1985	360.0	355.2	-	-	360.0	58.4	301.6	-
1986	1008.0	1147.4	-	-	1008.0	433.3	574.7	-
1987	748.8	781.8	-	-	748.8	261.0	487.8	-
1988	1365.6	1642.1	-	-	1365.6	781.6	584.0	-
1989	920.4	919.0	-	-	920.4	342.8	577.6	-
1990	1125.6	1339.3	-	-	1125.6	866.8	258.7	-
1991	1363.2	1259.4	-	-	1363.2	664.3	698.9	-
1992	1864.8	675.8	0	0	1864.8	1246.0	618.8	2000
1993	1969.2	1813.7	0	0	1969.2	1115.7	853.5	2000
1994	2054.3	2308.3	0	0	2308.3	1545.4	762.9	2500
1995	2213.9	2000.4	0	0	2000.4	1212.6	787.8	2500
1996	2735.7	2182.6	0	0	2182.6	1125.1	1057.4	2500
1997	2807.5	2378.7	0	0	2378.7	1043.6	1335.1	2500
1998	2434.0	2409.8	0	0	2409.8	918.6	1491.3	3500
1999	3255.2	3248.0	0	0	3248.0	1064.6	2183.4	4000
2000	3726.6	3726.1	0	0	3726.1	797.1	2929.0	4000
2001	3295.4	3296.2	0	0	3296.2	712.1	2584.2	4400
2002	4101.9	4101.4	0	0	4101.4	768.3	3333.1	4400
2003	3060.0	3041.0	12.6	3.5	3057.1	618.2	2438.9	4488
2004	3315.0	3311.0	0.2	0	3311.3	523.8	2787.5	4039
2005	2912.7	2907.6	0.1	0	2907.7	506.9	2400.8	4400
2006	2374.2	2373.5	0.1	0	2373.6	440.4	1933.3	4400
2007	1987.1	1998.4	0.1	0	1998.4	309.2	1689.2	3088
2008	1523.0	1522.8	0.1	0	1522.9	449.7	1073.2	3227
2009	1379.3	1378.2	<0.1	0	1378.2	409.1	969.1	3000
2010	1288.7	1287.1	1.3	0	1288.4	311.8	976.6	2566
2011	1235.5	1228.8	0.1	0	1228.9	252.4	976.5	2566
2012	853.4	847.7	<0.1	0	847.7	209.3	638.4	2566
2013	583.5	645.6	0	0	645.6	181.3	464.3	2329
2014	-	381.5	<0.1	0	381.5	95.9	285.6	2329
2015	-	359.0	<0.1	27.7	386.6	71.3	315.4	2417
2016	-	301.6	<0.1	48.9	350.5	128.2	222.4	1209
2017	-	348.0	0.1	0.1	348.1	105.7	242.4	605
2018	-	-	-	-	348.1*	105.7*	242.4*	600

* Catch from 2017 used for 2018 in the silver warehou assessment

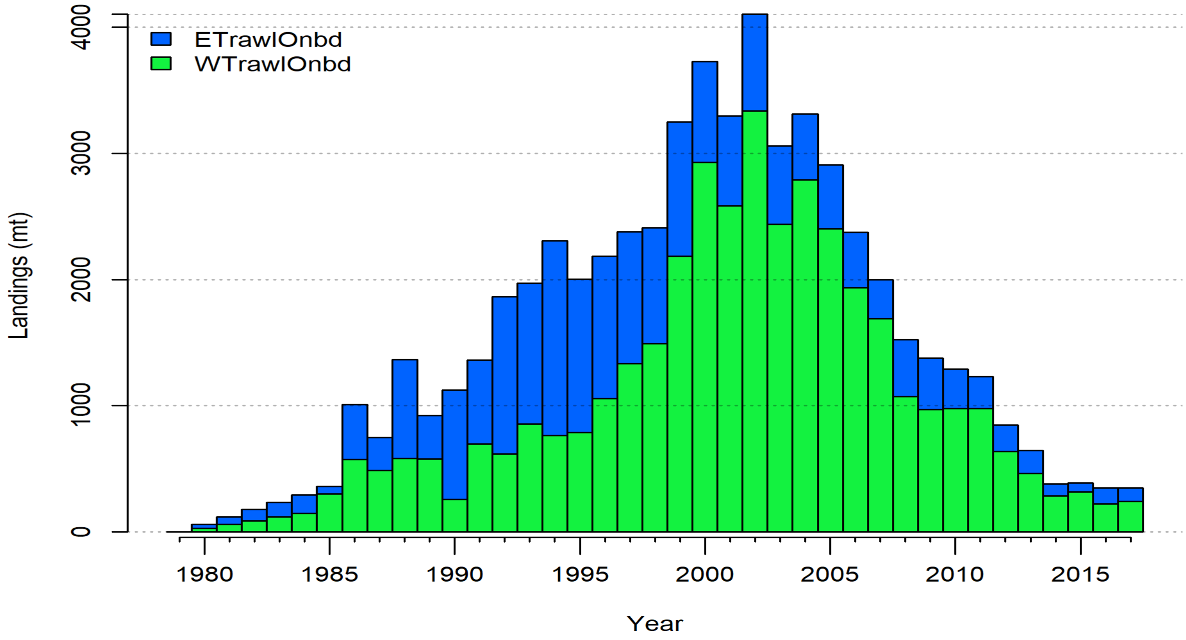


Figure 2. Total landed catch by fleet (stacked) for the eastern (blue) and western (green) fleets for silver warehou in the SESSF from 1980-2017 as used in this assessment.

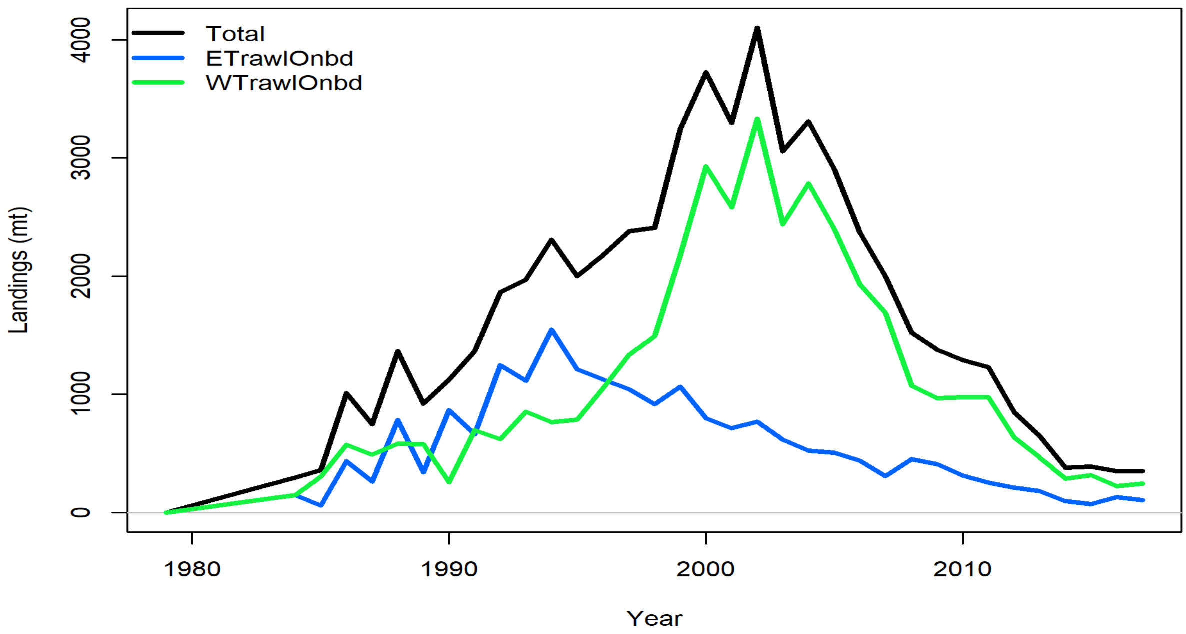


Figure 3. Total landed catch for the eastern (blue line) and western (green line) fleets for of silver warehou in the SESSF from 1979-2017 as used in this assessment.

1.5.4 Discard rates

Information on the discard catches of silver warehou is available from the integrated scientific monitoring program (ISMP) for 1993-2017. Prior to the 2015 assessment, there was no known pattern indicating when discarding was market-driven and when it was size-related, so the estimated discarded catch was added to the landed catch (Day *et al*. 2012). Thomson *et al.* (2015) provided evidence to support a change in discarding practice, from a mixture of market and sized based discarding prior to 2002, with only size based discarding occurring from 2002 onwards. The 2015 assessment estimated discarded catches separately for the eastern and western trawl fleets, both pre and post 2002, however, at that time the estimated fraction of discarded catch from ISMP data were only available for the stock as a whole (Upston and Thomson 2015).

Discard rates for Tier 1 assessments are required by fishing fleet. This means that the discard estimates for TAC purposes used for Tier 3 and 4 assessments which are provided in the discard report (Burch *et al.* 2018b) cannot be used in Tier 1 assessments. The discards from Burch *et al.* (2018b) are produced using a set of rules to determine, for the entire quota fishery, whether sufficient data are available to make an annual fishery wide discard estimate. The discard rates calculated for and input to Tier 1 stock assessments are used to fit retention selectivity curves, so individual year values are not greatly influential on model estimated discard rates.

The Tier 1 discard estimates have been updated in 2018 to more closely match the discard calculations in Bergh *et al.* (2009). These estimates use ratios of total discards to (retained + discard) catch on a per shot basis, rather than aggregated across a whole strata, which are then weighted up according to CDR landings within zone and season (N. Klaer, pers. comm.). This assessment separates the ISMP data east and west of 147° longitude and estimates the fraction of discarded catch separately for the eastern and the western trawl fleets. Discard fraction estimates are provided in Table 3.

Silver warehou are caught in the spawning fishery for blue grenadier and substantial catches have been taken in some years by factory trawlers that have operated since 1997. Previous assessments have adjusted the estimated discard fraction lower on the assumption that factory trawlers have fishmeal plants which apparently absorb all fish that might otherwise have been discarded. The September 2018 meeting of SERAG discussed the prevalence of the discarding of silver warehou by factory trawlers operating in the blue grenadier spawning fishery and recommended reviewing this assumption.

An investigation of the ISMP data identified records of factory vessels catching silver warehou exist in the ISMP database in 1998 and 1999 and between 2009 and 2013. In 1998, 1999, 2009 and 2013 there were no records of silver warehou being discarded in these years, however, there was some discarding of silver warehou from 2010 to 2012. For the years with observer coverage of the factory vessels we include the factory vessel data in the estimation of discarded silver warehou catches. For the years without observer coverage when factory vessels operated in this fishery (1997 and 2000 – 2008) we assume zero discarding by the factory vessels and adjust our discard rates lower by the proportion of factory vessel catch (Table 3).

Estimated discard fractions in the east were extremely variable with highs of 73% in 1995, 44% in 2003 and 43% in 2002 to <5% in 1993, 1994, 1999, 2007, 2010 and 2014 (Table 3). In the west estimated discard fractions were generally lower than those in the east with only the 1998 and 2000 being above 20%. The assessment did not fit the high discard fractions in either the east or the west with maximum discard rates in the east around 25% and <20% in the west (Figure 4). The discarded catches estimated within the assessment for years 1980 to 2017 are provided in Figures 5 and 6.

Table 3. Estimated discarded catch fraction by fleet, factory vessel catch as a proportion of landed catch by fleet and discard rates adjusted for factory vessel catch proportions by fleet.

	Estimated discard fraction		Proportion factory vessel catch		Observer	Adjusted discard fraction	
Year	East trawl	West trawl	East	West	coverage	East trawl	West trawl
1993	0.040	-	-	-	-	0.040	-
1994	0.012	0.087	-	-	-	0.012	0.087
1995	0.726	0.018	-	-	-	0.726	0.018
1996	0.214	0.159	-	-	-	0.214	0.159
1997	0.262	0.065	0	0.013	No	0.262	0.064
1998	0.099	0.366	0	0.034	Yes	0.099	0.366
1999	0.040	0.047	0.001	0.145	Yes	0.040	0.047
2000	0.100	0.208	0	0.288	No	0.100	0.148
2001	0.276	0.131	0.009	0.233	No	0.274	0.101
2002	0.192	0.086	0	0.415	No	0.192	0.050
2003	0.438	0.024	<0.001	0.276	No	0.438	0.018
2004	0.425	0.199	0	0.043	No	0.425	0.190
2005	0.192	0.067	0	0.001	No	0.192	0.067
2006	0.143	0.080	0	0.025	No	0.143	0.078
2007	0.016	0.103	0	0.011	No	0.016	0.102
2008	0.121	0.028	0	0.088	No	0.121	0.026
2009	0.073	0.020	0	0.029	Yes	0.073	0.020
2010	0.025	0.029	0	0.056	Yes	0.025	0.029
2011	0.224	0.036	0	0.062	Yes	0.224	0.036
2012	0.137	0.046	0	0.028	Yes	0.137	0.046
2013	0.067	0.040	0	0.026	Yes	0.067	0.040
2014	0.049	0.058	-	-	-	0.049	0.058
2015	0.386	0.094	-	-	-	0.386	0.094
2016	0.420	0.019	-	-	-	0.420	0.019
2017	0.344	0.077	-	-	-	0.344	0.077

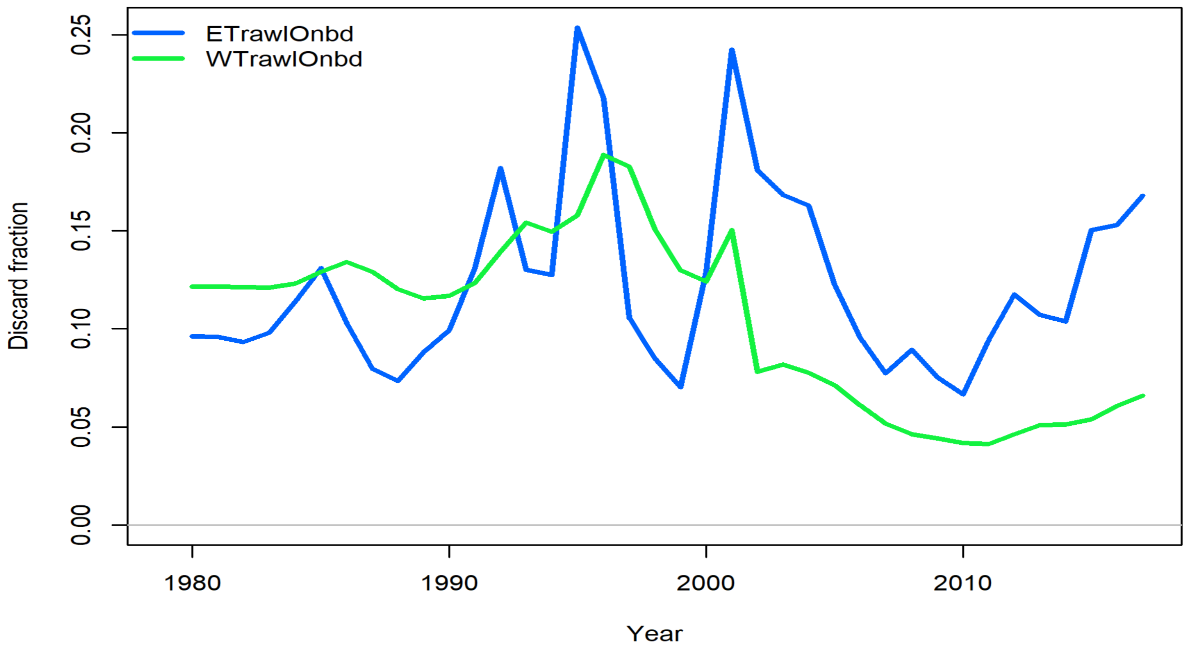


Figure 4. Estimates of discard fractions from the 2018 base case assessment for the eastern fleet (blue line) and the western fleet (green line) for silver warehou in the SESSF from 1980-2017.

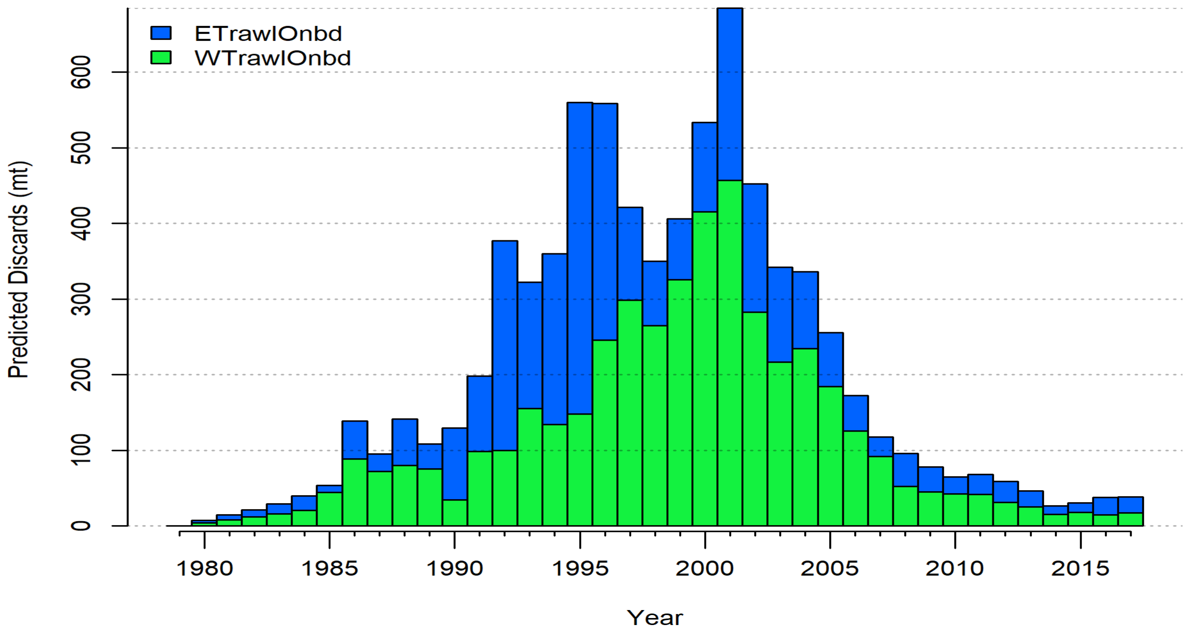


Figure 5. Estimated discards (stacked) of silver warehou from the 2018 base case assessment for the eastern (blue) and western (green) fleets 1980-2017.

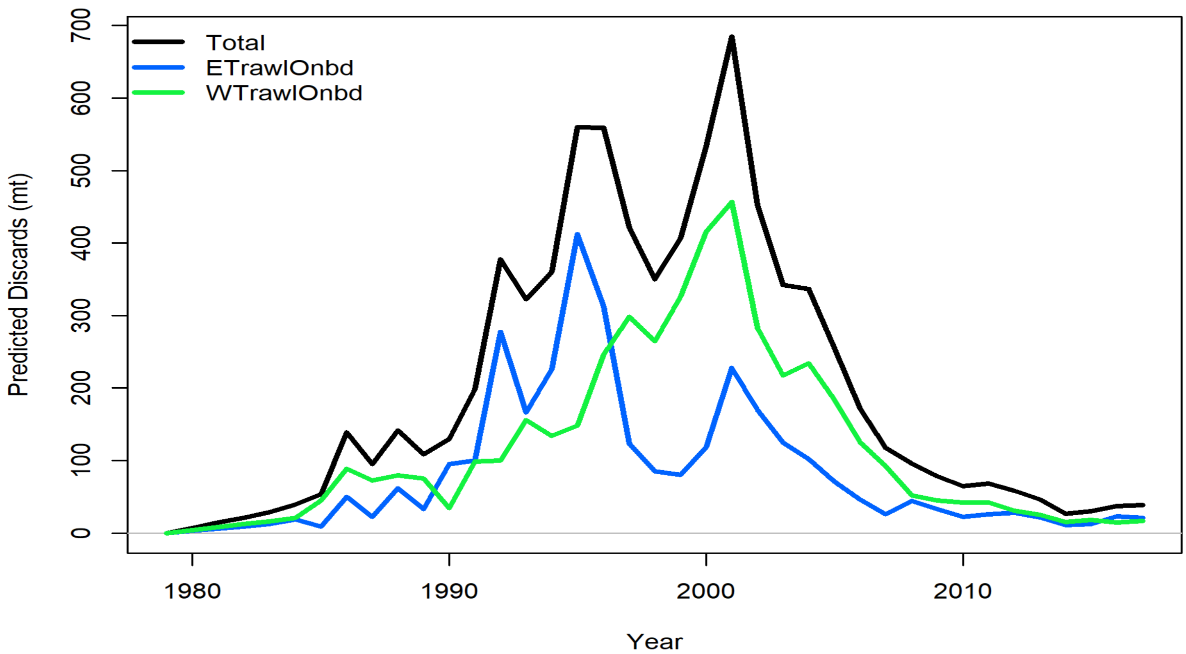


Figure 6. Estimated discards of silver warehou from the 2018 base case assessment 1980-2017.

1.5.5 Catch rate indices

Catch and effort data from the SEF1 logbook database from the period 1986 to 2017 were standardised using GLMs to obtain indices of relative abundance (Sporcic and Haddon 2018a, b) with the results listed in Table 4. Data used in this standardisation were restricted to trawl shots in depths between 0 and 600m from zones 10, 20 and 30 for the eastern trawl fleet and zones 40 and 50 for the western trawl fleet. Estimated standard deviations were obtained by fitting a loess smoother to each CPUE series which is standard practice for Tier 1 assessments in the SESSF.

Table 4. CPUE indices by fleet 1986-2017 with CVs used in the assessment.

Year	East trawl	East trawl CV	West Trawl	West trawl CV
1986	1.844	0.164	1.519	0.17
1987	1.799	0.164	1.719	0.17
1988	2.275	0.164	1.979	0.17
1989	1.887	0.164	1.670	0.17
1990	2.404	0.164	1.107	0.17
1991	1.454	0.164	1.186	0.17
1992	1.620	0.164	0.897	0.17
1993	1.589	0.164	1.250	0.17
1994	1.764	0.164	1.145	0.17
1995	1.488	0.164	0.945	0.17
1996	1.212	0.164	1.059	0.17
1997	1.200	0.164	1.248	0.17
1998	0.991	0.164	1.461	0.17
1999	0.868	0.164	1.203	0.17
2000	0.703	0.164	1.175	0.17
2001	0.659	0.164	0.887	0.17
2002	0.768	0.164	0.942	0.17
2003	0.700	0.164	0.978	0.17
2004	0.819	0.164	1.071	0.17
2005	0.757	0.164	1.171	0.17
2006	0.639	0.164	1.032	0.17
2007	0.502	0.164	1.043	0.17
2008	0.588	0.164	0.830	0.17
2009	0.666	0.164	0.721	0.17
2010	0.489	0.164	0.655	0.17
2011	0.424	0.164	0.631	0.17
2012	0.383	0.164	0.468	0.17
2013	0.479	0.164	0.438	0.17
2014	0.329	0.164	0.417	0.17
2015	0.228	0.164	0.451	0.17
2016	0.197	0.164	0.329	0.17
2017	0.276	0.164	0.375	0.17

1.5.6 Length composition data

In 2010 the RAGs decided to include both port and onboard retained length frequency data (for both historic and current years) in future assessments, whereas in previous assessments only port data have been used (Tuck and Fay 2009). In 2012, the port and onboard length composition data was combined to give one length distribution for each year of data. For the 2015 assessment, port and onboard length composition data were both used separately, with the gear selectivity estimated jointly from both port and onboard data from each fleet (eastern and western trawl) and this decision was retained to the 2018 assessment. There were some length data available from the SPF in 2015 and 2016, however, this was excluded because of the SPF use mid-water trawl. Should silver warehou continue to be caught in the SPF it may be possible to incorporate the SPF as a separate fleet in the assessment and estimate selectivity from SPF length data.

For onboard data, the number of shots is used as the initial sample size before the length frequency data are re-weighted in the tuning process (see Section 2.2.2). This is considered to be more representative of the information content in the length frequencies than the number of fish measured. For port data, the number of shots is not available, but the number of trips is used instead. In the 2018 assessment, the initial sample size associated with each length frequency in the assessment is the number of shots or trips. However, data was excluded for years with less than 100 individual fish measured, as small samples are potentially unrepresentative. Sample sizes for retained length frequencies, including both the number of individuals measured and numbers of shots or trips, are listed in Table 5 for each fleet and year for 1991 to 2017.

Table 5. Number of retained lengths, shots and trips included in the base case assessment by fleet 1991-2017.

	Onboard sampling				Port sampling			
	East trawl		West trawl		East trawl		West trawl	
Year	Lengths	Shots	Lengths	Shots	Lengths	Trips	Lengths	Trips
1991	-	-	-	-	273	4	-	-
1992	-	-	-	-	1648	9	1769	15
1993	-	-	-	-	1087	6	1431	11
1994	-	-	-	-	215	4	1802	22
1995	-	-	-	-	500	5	4651	37
1996	293	4	122	1	1014	10	6023	53
1997	1815	22	1883	33	1762	18	8874	82
1998	2959	34	2671	43	6386	63	9704	89
1999	2449	32	1952	19	6347	68	7742	75
2000	1642	17	3584	46	8239	48	5424	47
2001	1446	23	4610	47	7958	60	6978	61
2002	2554	37	4047	26	12979	85	9064	83
2003	2005	34	5019	44	5431	37	3359	28
2004	2147	33	3679	33	4868	34	2638	23
2005	2028	25	6617	60	9007	46	3319	28
2006	1847	33	3763	32	7994	49	855	9
2007	173	12	-	-	728	5	491	2
2008	440	18	198	8	971	6	-	-
2009	370	10	853	41	2135	27	163	2
2010	1391	30	1285	37	1139	22	-	-
2011	371	17	1140	61	1288	40	-	-
2012	807	31	991	31	1252	40	-	-
2013	730	29	1523	49	1720	45	141	1
2014	142	4	900	17	1391	26	152	2
2015	282	11	934	25	1755	30	-	-
2016	452	14	656	34	1476	20	240	10
2017	404	12	549	17	1859	27	195	4

Discarded length frequencies were only available for onboard samples as discarded fish are not landed in port. Sample sizes for discarded length frequencies including both the number of individuals measured and numbers of shots are listed in Table 6 for each fleet and year for the period 1994-2017.

Table 6. Number of discarded lengths and shots included in the base case assessment by fleet 1994-2017.

	East trawl		West trawl	
Year	Lengths	Shots	Lengths	Shots
1994	-	-	224	2
1995	456	5	930	8
1996	-	-	1421	10
1997	234	3	232	18
1998	-	-	1998	39
1999	-	-	477	6
2000	210	3	296	18
2001	888	15	1371	25
2002	1805	34	1257	8
2003	1364	23	191	3
2004	3319	52	1111	16
2005	1332	19	658	15
2006	140	13	-	-
2008	150	9	-	-
2009	127	2	-	-
2010	131	6	-	-
2011	159	9	132	23
2012	471	13	-	-
2013	109	13	178	8
2014	163	2	-	-
2015	280	10	-	-
2016	499	15	-	-
2017	465	17	723	8

1.5.7 Age composition data

Age-at-length measurements, based on sectioned otoliths provided by the CAF, were available for the years 1988 and 1993 to 2017 east and west of 147° longitude (Table 7).

Table 7. Number of samples in the conditional age-at-length data in the base case assessment 1988-2017.

Year	East	West	Total
1988		132	132
1993	171	163	334
1994	186	173	359
1995	157	294	451
1996	317	198	515
1997	443	123	566
1998	404	181	585
1999	220	562	782
2000	139	267	406
2001	366	631	997
2002	327	395	722
2003	122	302	424
2004	126	179	305
2005	125	352	477
2006	132	263	395
2007	237	69	306
2008	313	234	547
2009	494	327	821
2010	687	135	822
2012	775	214	989
2013	89	383	472
2014	153	153	306
2015	165	218	383
2016	206	273	479
2017	220	292	512
Total	6574	6513	13087

An estimate of the standard deviation of age-reading error for the entire fishery (east and west combined) was calculated by André Punt (pers. comm. 2018) using data supplied by Kyne Krusic-Golub of Fish Ageing Services Pty Ltd and a variant of the method of Richards *et al.* (1992) (Table 8). The implied age distributions are obtained by transforming length frequency data to age data by using the information contained in the conditional age-at-length data from each year.

Table 8. Estimated uncertainty in otolith age determinations by age class.

Age	St. dev.
0	0.1537
1	0.1537
2	0.2311
3	0.3074
4	0.3828
5	0.4571
6	0.5305
7	0.6028
8	0.6742
9	0.7446
10	0.8141
11	0.8827
12	0.9503
13	1.017
14	1.0828
15	1.1478
16	1.2118
17	1.2751
18	1.3374
19	1.3989
20	1.4597
21	1.5195
22	1.5786
23	1.6369

1.5.8 Fishery Independent Survey (FIS) estimates

A fishery independent trawl survey (FIS) has been undertaken biennially in winter between 2008 and 2016 (Knuckey *et al.* 2017). Indices from the FIS were re-estimated for the east (SESSF zones 10, 20 and 30) and the west (SESSF zones 40 and 50) with coefficients of variation calculated for each fleet (Table 9). At the SERAG meeting in September 2018 it was agreed that FIS would be removed from the base case and instead presented as a sensitivity (see Section 3.2). The utility of using the length composition data from the FIS to estimate FIS selectivity has yet to be investigated and we assumed the FIS has the same selectivity as the respective trawl fleets.

Table 9. FIS derived abundance indices for silver warehou with corresponding coefficient of variation (cv).

Year	East abundance (CV)	West abundance (CV)
2008	149.0 (0.576)	110.7 (0.232)
2010	55.6 (0.576)	25.9 (0.232)
2012	218.7 (0.576)	25.6 (0.232)
2014	14.7 (0.576)	32.2 (0.232)
2016	284.8 (0.576)	44.8 (0.232)

1.5.9 Input data summary

The data used in this assessment is summarised in Figure 7, indicating which years the various data types were available.

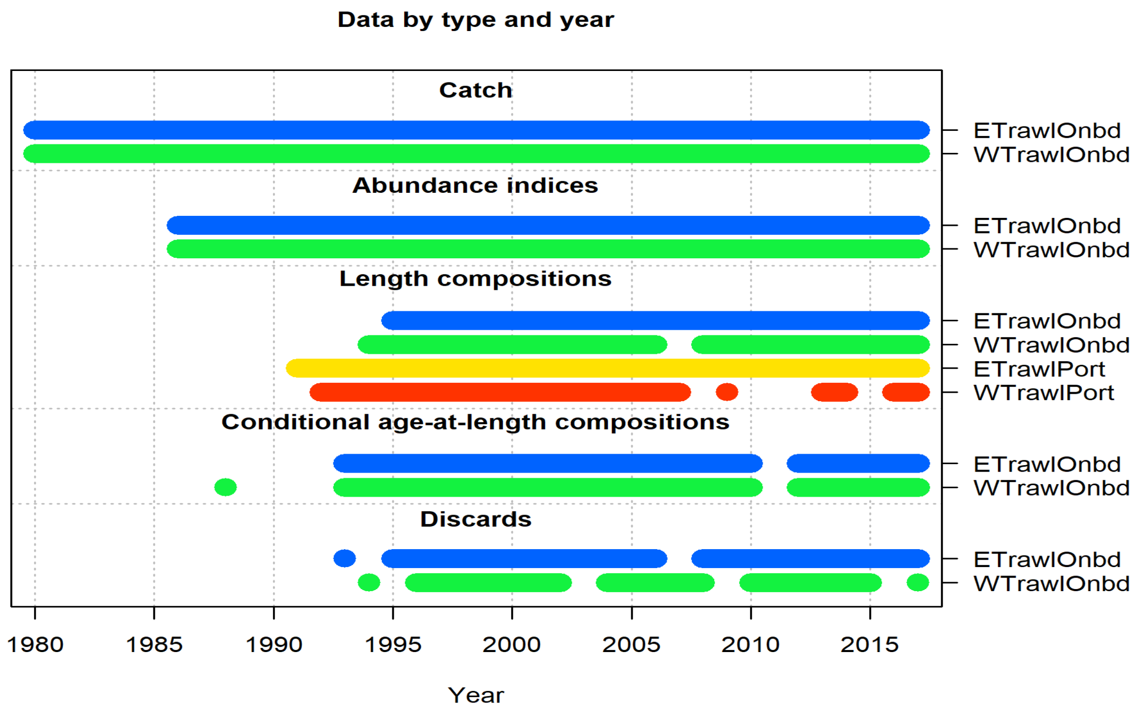


Figure 7. Summary of input data used for the silver warehou assessment.

1.6 Stock assessment method

1.6.1 Population dynamics model and parameter estimation

In 2015, a single-sex single-fleet stock assessment for silver warehou was conducted using the software package Stock Synthesis (version SS-V3.24U, Methot 2015). Stock Synthesis is a statistical age- and length-structured model which can allow for multiple fishing fleets, and can be fitted simultaneously to the types of information available for silver warehou. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the SS3 user manual (Methot *et al.* 2018) and is not reproduced here. This year, the model was translated to the latest version of Stock Synthesis (version SS-V3.30.12, Methot *et al.* 2018). A comparison of parameter estimates and population trajectories were visually indistinguishable between the two versions of Stock Synthesis (see Figures 1-3 Burch *et al.* 2018a).

Some key features of the base case model are:

1. Silver warehou constitute a single stock with in the area of the fishery.
2. The eastern (SESSF zones 10, 20 and 30) and western (SESSF zones 40 and 50) trawl fleets were modelled separately with separate catches, catch rates, length frequencies and selectivity

3. The population was at its unfished (virgin) biomass with the corresponding equilibrium (unfished) age-structure at the start of 1979.
4. Selectivity for the trawl fleets is length-specific, logistic and time-invariant. The two parameters of the selectivity function were estimated within the assessment for each fleet.
5. Retention is estimated separately for two time blocks (1980-2001 and 2002-2014) for each fleet. The slope and intercept parameters were estimated for each fleet, but the asymptote was fixed at 100%. Separate discard time series were used for the east and west trawl fleets assuming a CV of 0.35.
6. The rate of natural mortality, *M*, is assumed to be constant with age, and also time-invariant. The base-case value for *M* is 0.30 yr^{-1}.
7. Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at virgin spawning biomass, R_0, and the steepness parameter, *h*. Steepness for the base-case analysis is set to 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1980 to 2012. Deviations are not estimated prior to 1980 because there are insufficient data prior to 1980 to permit reliable estimation of recruitment residuals. Deviations are not estimated after 2014 as there would be insufficient numbers of fish recruited to the fishery or seen in the discards to reliably estimate recruitments from 2015 (the age at which 50% of fish have been recruited to the trawl fishery is approximately four). This final year for estimating recruitment deviations is confirmed by observing the increase in asymptotic standard error estimate of the recruitment deviation produced by Stock Synthesis.
8. A plus-group is modelled at age 23 years.
9. Any length frequency data with less than 100 individual fish measured in a year were excluded as unrepresentative. The number of shots was used as the sample size for onboard length frequencies and the number of trips for port based length frequencies, with a cap at 100 shots (although in practice this cap was not needed for this assessment). These sample sizes were then further tuned so that the input sample size was equal to the effective sample size calculated by the model. The tuning procedure is described in Section 2.2.2.
10. Onboard and port length frequencies were fitted separately, with a common selectivity estimated from these two sources of length frequency data.
11. Growth of silver warehou is assumed to be time-invariant, in that there is no change over time in mean size-at-age, with the distribution of size-at-age being estimated along with the remaining growth parameters within the assessment. No differences in growth related to gender are modelled, because the stock is modelled as a single-sex.

This forms the base case model for the 2018 silver warehou assessment.

1.6.2 Tuning method

Iterative rescaling (reweighting) of input CVs or input effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council 2016). Sampling standard deviations/ CVs and stage-1 effective sample sizes for most of the data (CPUE, survey indices, composition data) used in fisheries assessments underestimate their true variance by only reflecting measurement or estimation error and not including process (or model) error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated within the model. In SS-V3.30 it is possible to estimate an additional standard deviation parameter to add to the input CVs for the abundance indices (CPUE).

1. Set the standard error for the log of relative abundance indices (CPUE or FIS) to their estimated standard errors to the standard deviation of a loess curve fitted to the original data - which will provide a more realistic estimate compared to that obtained from the original statistical analysis. SSV-3.30 then allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

An automated iterative tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by SSv3.30 at each step.

For the age and length composition data:

3. multiply the initial (stage-1) sample sizes by the sample size multipliers for the conditional age-at-length data using the approach of Punt (2017).
4. similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the 'Francis method' (Francis 2011).
5. repeat steps 2 - 4, until all are converged and stable (with proposed changes < 1 – 2%).

This procedure constitutes current best practice for tuning assessments.

1.6.3 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith *et al.,* 2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system for fishing years 2006- 2012. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of four Tier levels depending on the quality and quantity of data for that stock. Silver warehou is assessed as a Tier 1 stock and it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. For the 2013 TACs AFMA has directed that the 20:40:40 (B_{lim}:B_{msy}:F_{targ}) form of the rule will be used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2008) has determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} this form of the rule is equivalent to a 20:35:48 strategy.

1.6.4 Sensitivity tests

A number of standard sensitivity tests are used to examine the sensitivity of the results of the 2018 base case to some of the assumptions and data inputs:

(a) Include the time series of winter FIS surveys with indices split east.

(b) M = 0.25 and 0.35 yr^{-1}.

(c) h = 0.65 and 0.85.

(d) 50% maturity occurs at length 34 and 40cm.

(e) σ_R = 0.6 and 0.8.

(f) Recruitment deviations estimated to 2013 and 2015.

(g) Double and halve the weighting on the CPUE series.

(h) Double and halve the weighting on the length composition data.

(i) Double and halve the weighting on the age-at-length data.

(j) Double the reported catch form 1998 to 2002.

The last sensitivity, doubling the reported catch from 1998 to 2002, came about following a suggestion from industry at the September 2015 Slope RAG meeting, to explore the impact of any possible mis-reporting of silver warehou landings in this period.

1.6.5 Low recruitment scenarios

To explore the potential impact of setting a multi-year TAC without updating this assessment, scenarios were run where the recruitment in the period from 2015-2023 was assumed to be below average. When the harvest control rules are applied and forward projections are made, recruitment deviations from 2015 onwards are set to zero, as there is insufficient information to estimate recruitment in this period. This essentially assumes average recruitment for the given level of spawning biomass for the period 2015 onwards.

Given that eleven of the last twelve recruitment events are estimated to be below average (Figure 16) and that the last two estimated recruitments (2013 and 2014) are just below average and could be revised down in the future with additional data, and given that catches and catch rates have been declining for the last ten years, it seems unlikely that catches will return to the projected RBC levels given in Table 12. Indeed it seems plausible that recruitment may remain below average for the next few years. As such, the SERAG has requested scenarios be considered with below average future recruitment.

1.6.6 Retrospective analysis

The last two silver warehou assessments have shown below average recruitment, declines in CPUE and catch even though catches have been well below the TAC. The structure, data and tuning protocols of the silver warehou assessment has changed since Day *et al.* (2012). Because the stock may be on or near the limit reference point we undertake a retrospective analysis (Cadrin and Vaughan 1997, Mohn 1999) to identify whether below average recruitment and declining stock size would have been identified by previous assessments using the same assumptions, data and tuning as the 2018 assessment.

The retrospective analysis was undertaken using the following procedure

1) Two years of data was removed from the 2018 base case assessment
2) Time dependent model parameters (e.g. last year of recruitment) were changed to be two years earlier
3) The model was retuned using the procedure described in Section 2.2.2 to create a base case assessment for 2016
4) Steps 1 – 3 were repeated to create assessments for 2014 and 2012.

Trends in spawning biomass and estimated recruitment are then examined to help understand how reliable the most recent few years of estimated recruitments and spawning biomass are in the 2018 assessment.

1.6.7 MCMC analysis for the base case

A Bayesian assessment was undertaken as part of the 2018 silver warehou assessment because the base case assessment showed that the maximum likelihood estimate of spawning biomass was near the limit reference point of 20% of its unfished level between 2013 and 2016, with the lower 95^{th} percent asymptotic confidence intervals being below the limit reference point in those years.

Bayesian frameworks for stock assessment better accommodate the uncertainties relating to a particular model structure and its parameter values, however, they still remain computationally intensive and require the specification of appropriate prior distributions (Punt and Hilborn 1997). Stock Synthesis version 3.30 is programmed using the software Auto Differentiation Model Builder (ADMB, Fournier et al. 2012) version 11.6 which implements Bayesian model frameworks using Markov chain Monte Carlo (MCMC) implemented using the Metropolis-Hastings algorithm (Gelman *et al.* 2013).

We ran seven MCMC chains of the base case model. The starting values of the parameters for each chain were jittered (slightly different between chains). Each chain was run for 2,000,000 iterations with the first 300,000 iterations discarded (the burn-in period). Each chain was thinned by saving every $2{,}000^{th}$ iteration and the remaining values used to evaluate chain convergence and estimate model parameters with their associated uncertainty. We then calculated the probability the spawning biomass was above 20% of the unfished level (the limit reference point) between 2012 and 2019.

Convergence of MCMC chains was assessed using the Geweke test (Geweke 1992), the Heidelberger and Welch test (Heidelberger and Welch 1983) and by the examination of trace plots. The R packages r4ss (Taylor et al. 2018) and CODA (Plummer et al. 2006) were used to undertake the tests and create the trace plots presented in Appendix B.

1.6.8 Summary statistics

The results of the base-case analysis and the sensitivity tests are summarized using the following quantities:

(a) SB_0 the average unexploited spawning biomass,

(b) SB_{2019} the spawning biomass at the start of 2019,

(c) SB_{2019}/SB_0 the 2019 spawning biomass expressed as a percentage of the virgin spawning biomass

(d) $-lnL$ the negative of the logarithm of the likelihood function (this is the value minimised when fitting the model, thus a lower value implies a better fit to the data),

(e) 2019 RBC 20:35:48 the 2019 RBC calculated using the 20:35:48 harvest rule.

(f) Long term RBC 20:35:48 the long term RBC calculated using the 20:35:48 harvest rule.

2 The 2018 assessment of silver warehou

2.1 The base case

2.1.1 Transition from the 2015 base case to the 2018 base case

The assessment models presented in Day *et al.* (2015) used data up to 2014. The major changes in the 2018 assessment are: updating the version of Stock Synthesis to version 3.30.12 (Methot *et al.* 2018); the addition of new data for 2015, 2016 and 2017 (including new catch, discard, CPUE, length frequency and age-at-length data); separating catch, catch rate and length data into eastern and western trawl fleets (each with their own selectivity pattern); increasing the second period of size based discarding to end in 2017; adding the 2016 abundance index from the east and west FIS; the estimation of three more years of recruitment; and the implementation of a new tuning procedure. The main change to the assessment procedure and Stock Synthesis that relates to assessments in the SESSF is a revised tuning procedure (Section 2.2.2).

These revisions, with a bridging analysis, were considered by Burch *et al*. (2018a) and showed changes in the time series of spawning biomass including a decline in the estimated 2016 spawning biomass when compared to the 2015 assessment (Day *et al.* 2015). At the September 2018 meeting of SERAG there was discussion of continued below average recruitment estimates, the discarding practices of factory trawlers and the robustness of the silver warehou CPUE and catch data in regard to historical mixed reporting of blue warehou and silver warehou. SERAG accepted the preliminary base case assessment with two modifications: removal of the FIS from the base case (instead including it as a sensitivity) and not estimating the 2015 recruitment.

2.1.2 Corrections to the 2018 preliminary base case

Following the September 2018 SERAG meeting investigations into the catch and discard data identified a number of issues that resulted in modifications to the catch, discard and length frequency presented in preliminary base case assessment (Burch *et al.* 2018a). These changes are outlined below and described in more detail elsewhere in this report.

a. Correction of an error in the catch time series that arose from the removal of discarded catches in the 2015 assessment (Section 2.1.3).

b. Updating the catches from 1994 onwards to account for updates to the database made by AFMA. Catches prior to 1994 were retained due to problems in distinguishing silver warehou from blue warehou in logbooks (Section 2.1.3).

c. Inclusion of catches from the GHAT and the SPF in the assessment (Section 2.1.3).

d. Removal of length frequency data from the SPF in 2015 and 2016 (Section 1.5.6).

e. Separating the estimates of discarded catch into eastern and western trawl fleets (the 2015 assessment used combined series) and updating time series (Section 2.1.4).

f. Incorporating discarded catch estimates from factory trawlers into overall discard estimates where these vessels had ISMP observer coverage (Section 2.1.4).

g. Assuming a lognormal error structure when fitting to the estimated discard fractions in the assessment (previously Normal errors were incorrectly assumed).

Along with the removal of the FIS from the base case and not estimating recruitment in 2015, these changes resulted in slight differences in the time series of relative spawning biomass (Figure 8). One difference between the final base case and the preliminary assessment presented to the September 2018 SERAG meeting is that the 2014 recruitment is now below average, when previously it was average (Figure 9). Note that the 2015 recruitment is not estimated in the final base case.

These results were communicated to AFMA and the SERAG chair in October and this model has been used as the base case for the 2018 silver warehou stock assessment.

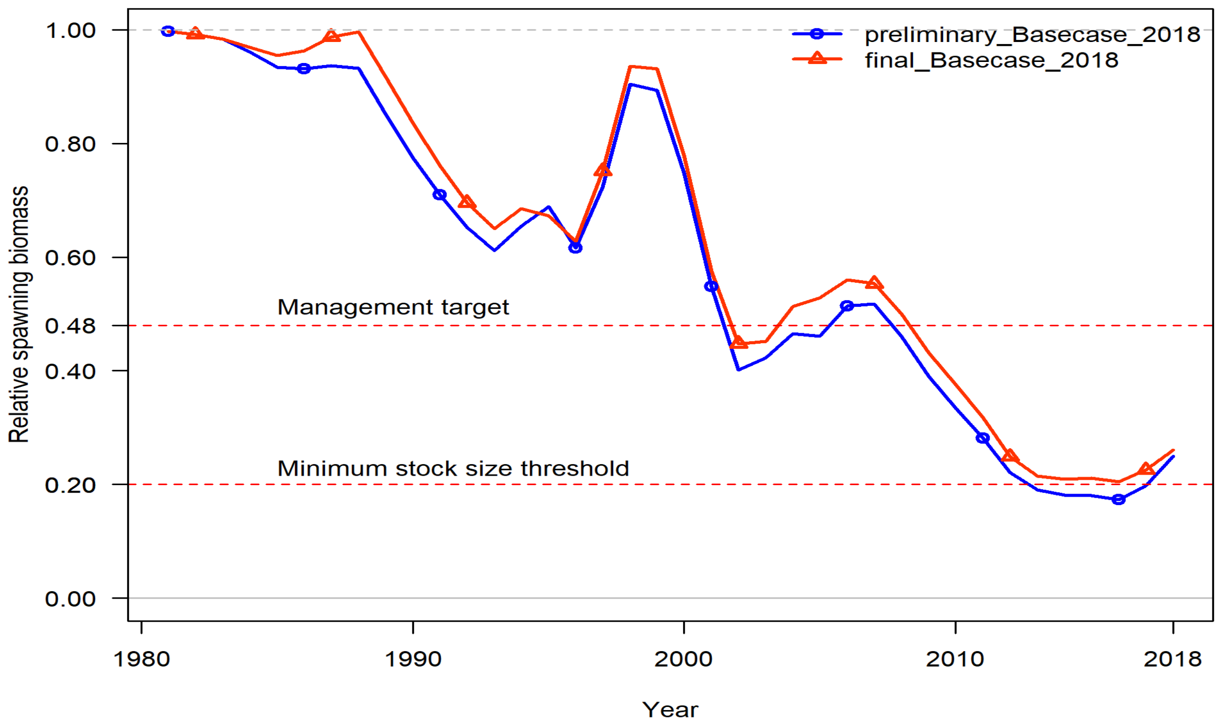


Figure 8. Comparison of the time-series of relative spawning biomass for the 2018 preliminary base case assessment from Burch *et al.* (2018a) and the final 2018 base case.

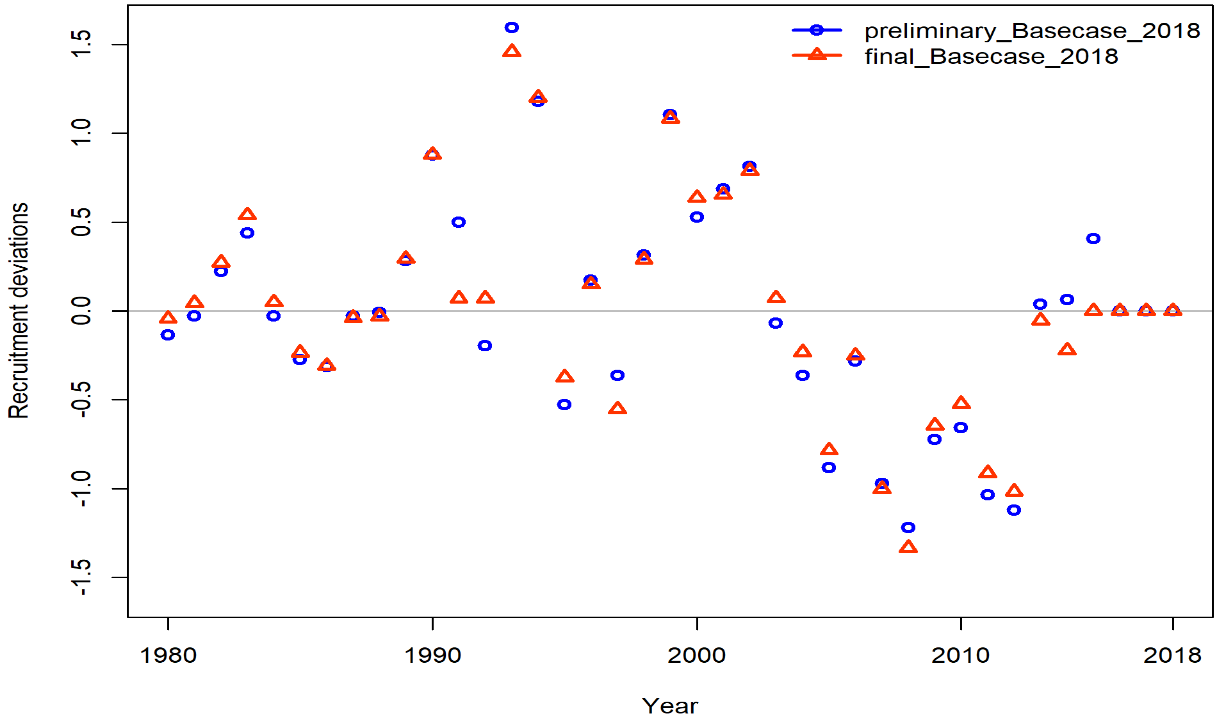


Figure 9. Comparison of the recruitment time series for the 2018 preliminary base case assessment from Burch *et al.* (2018a) with revision presented to SERAG in September and the final 2018 base case.

2.1.3 Parameter estimates of the base case model

Figure 10 shows the estimated growth curve for silver warehou. All growth parameters are estimated. The estimates of the growth parameters are: (a) L_{min}=14.82cm, (b) L_{max}=51.21cm, (c) K=0.312 yr^{-1}, and (d) cv of growth = 0.0808. This growth curve is very similar to the growth curve estimated in the 2015 assessment.

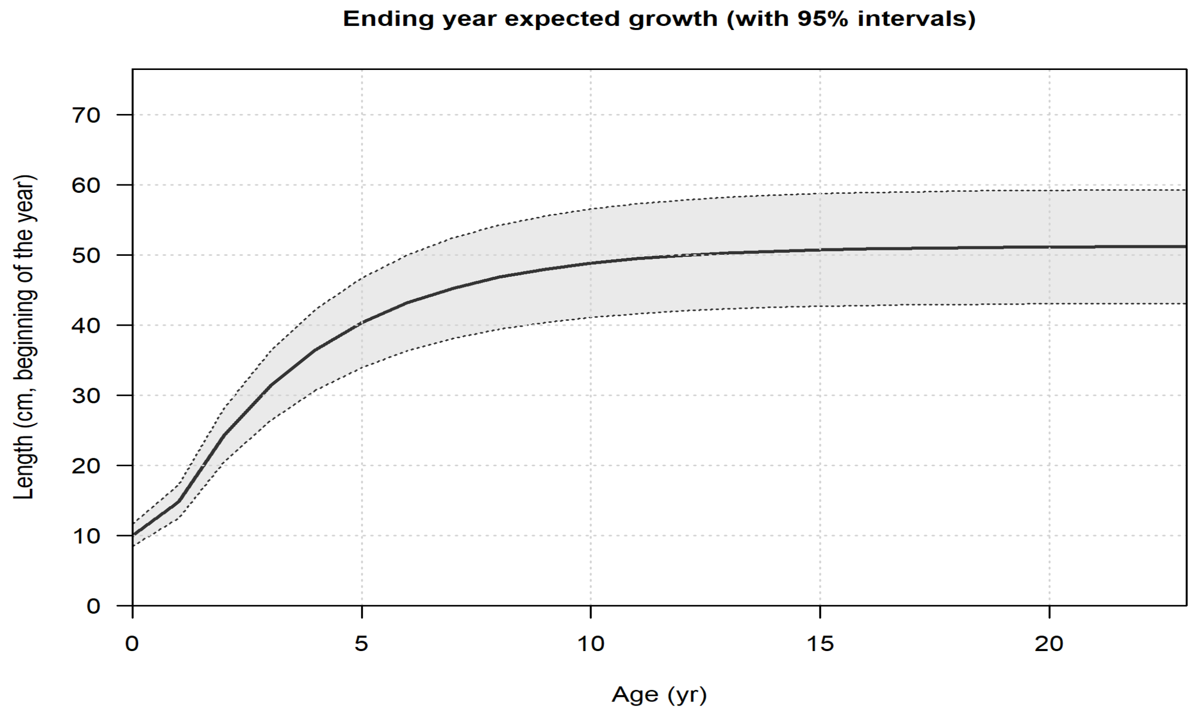


Figure 10. The model estimated growth function for silver warehou for the base case.

Figure 11 shows the estimated time varying retention and selectivity curves for the east and west trawl fleets for silver warehou. The parameters that define this selectivity function including the length at 50% selection and the spread. The estimates of these parameters for the base-case analysis are 22.82cm and 3.48cm respectively for the east and 39.87cm and 11.24cm for the west (Table 1). While length at 50% selection has remained stable in the west compared to the 2015 assessment (39.59cm) it has declined almost 2cm in the east (from 24.66cm).

The estimates for the parameters that defines in the time block 2002-2017 are 29.29cm and 3.29cm respectively for the east and 28.72cm and 4.84cm for the west. The estimate of the parameter that defines the initial numbers (and biomass), *$ln(R_0)$*, is 9.379 for the base case.

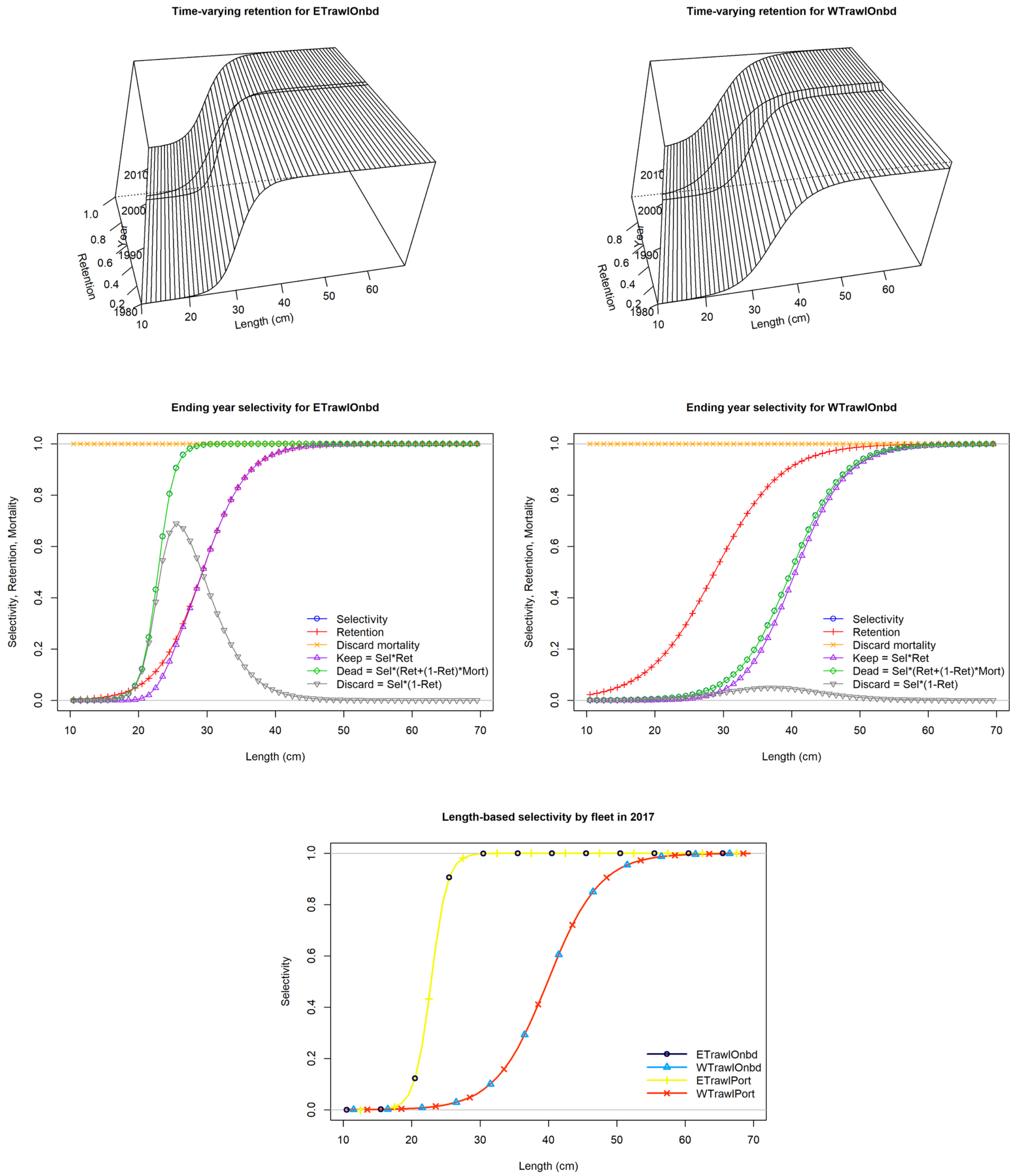


Figure 11. Estimated retention function (discard pattern) with two time blocks (1980-2001, and 2002-2017) for east (top left) and west (top right) trawl fleets. Selectivity and discard patterns for east (middle left) and west (middle right) fleets, and east and west selectivity patterns plotted together (bottom).

2.1.4 Fits to the data for the base case model

The fits to the catch rate indices for the base case are good for the west trawl fleet and poor for the east trawl fleet (Figure 12). For the east trawl fleet, the model underestimates CPUE between 1986 and 1995, then overestimates CPUE from 1996 to 2008, between 2009 and 2014 the fit is good and then the model overestimates the last three data points (2015, 2016, 2017). Fits to CPUE for the west trawl fleet are good, with the model following trends in CPUE with the exception of 2002 – 2005 and the two most recent years (2016 and 2017) which it overestimates. Overestimation of the most recent CPUE data points was also seen in previous assessments (Day *et al.* 2012, 2015).

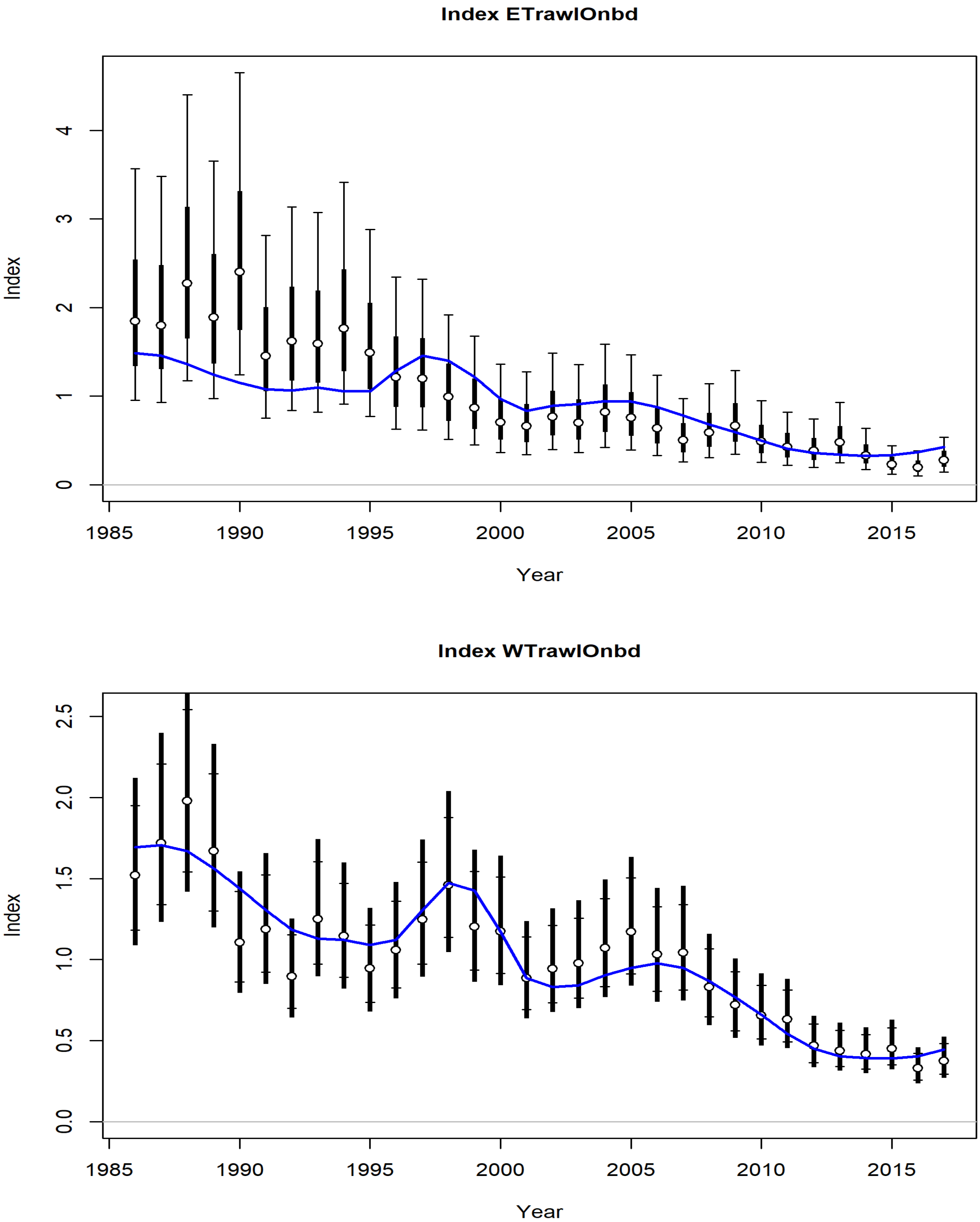


Figure 12. Observed (circles) and model-predicted (blue line) catch-rates for silver warehou for the east (top) and west (bottom) trawl fleet versus year for the base case analysis. The vertical lines indicate approximate 95% confidence intervals for the data.

Difference in the length frequency distributions between port and onboard samples, particularly in east, means that it is difficult for the assessment to fit the aggregated retained length frequency (Figure 13). The eastern trawl retained fits are not as good as the western trawl, and the western trawl discard length frequencies are quite variable and hence difficult to fit well. The discard length frequencies in the east fit quite well (Figure 13). These patterns are very similar to those in the last assessment (Day *et al.* 2015).

Annual fits and residuals are included in Appendix A. While the annual fits are not as good as the aggregated fits, the length frequency data appears to be very variable, especially for the eastern trawl fleet. This may reflect spatial and temporal differences in collection of this data between years and hence this length frequency data may not be as representative as we would like, similar to those of the 2015 assessment. The implied fits to age show similar patterns to the length data, with better fits in the west, than the east, but given this implied fit to age is derived from length frequency data, it is not surprising to see similar trends.

The onboard sampling data contains some fish < 20cm for the eastern discards in 2006, 2013 and 2015 and in the eastern and western retained catch in 2015. The 2006 and 2013 discards also appeared in the 2015 assessment and, although they are not fitted to by either assessment, should be investigated for future assessments.

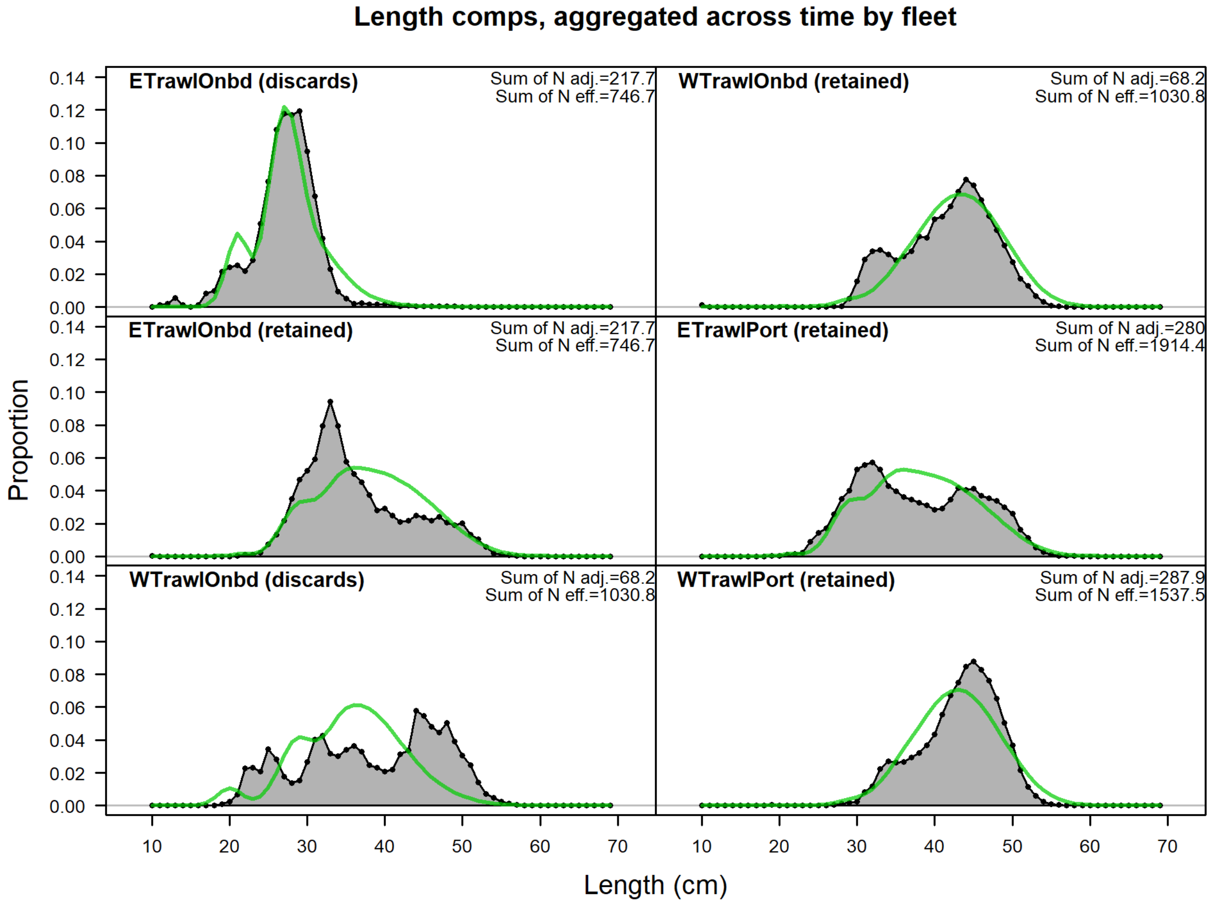


Figure 13. Aggregated length compositions for the onboard and port data sources in both the east and west. Observed data are grey and the fitted value is the green line.

The fits to the discard fractions are poor in the east where the model has not fitted to annual discard rates above 25% (Figure 14). In the west, fits to discard fractions are somewhat better, particularly after 2002, however the assessment still fails to fit the two annual discard fractions above 20%. Inclusion of the discard data split into eastern and western trawl fleets resulted in difficulties with model convergence which suggests a conflict between the discard data and other data sources within the model. The difficulties with convergence were resolved by increasing the CV on the discards from 0.25 to 0.35 and retuning the model after each model or data change to the preliminary base case assessment presented to the September 2018 SERAG meeting.

Given the extreme variability in annual discard fractions, particularly in the east, it is perhaps not surprising the assessment fails to fit the annual discard fractions >25% on the east and 20% in the west. This, along with the apparent increase in discarding in the east from 2015 – 2017 suggests that discarding of silver warehou and its impact on the assessment requires further exploration in future assessments.

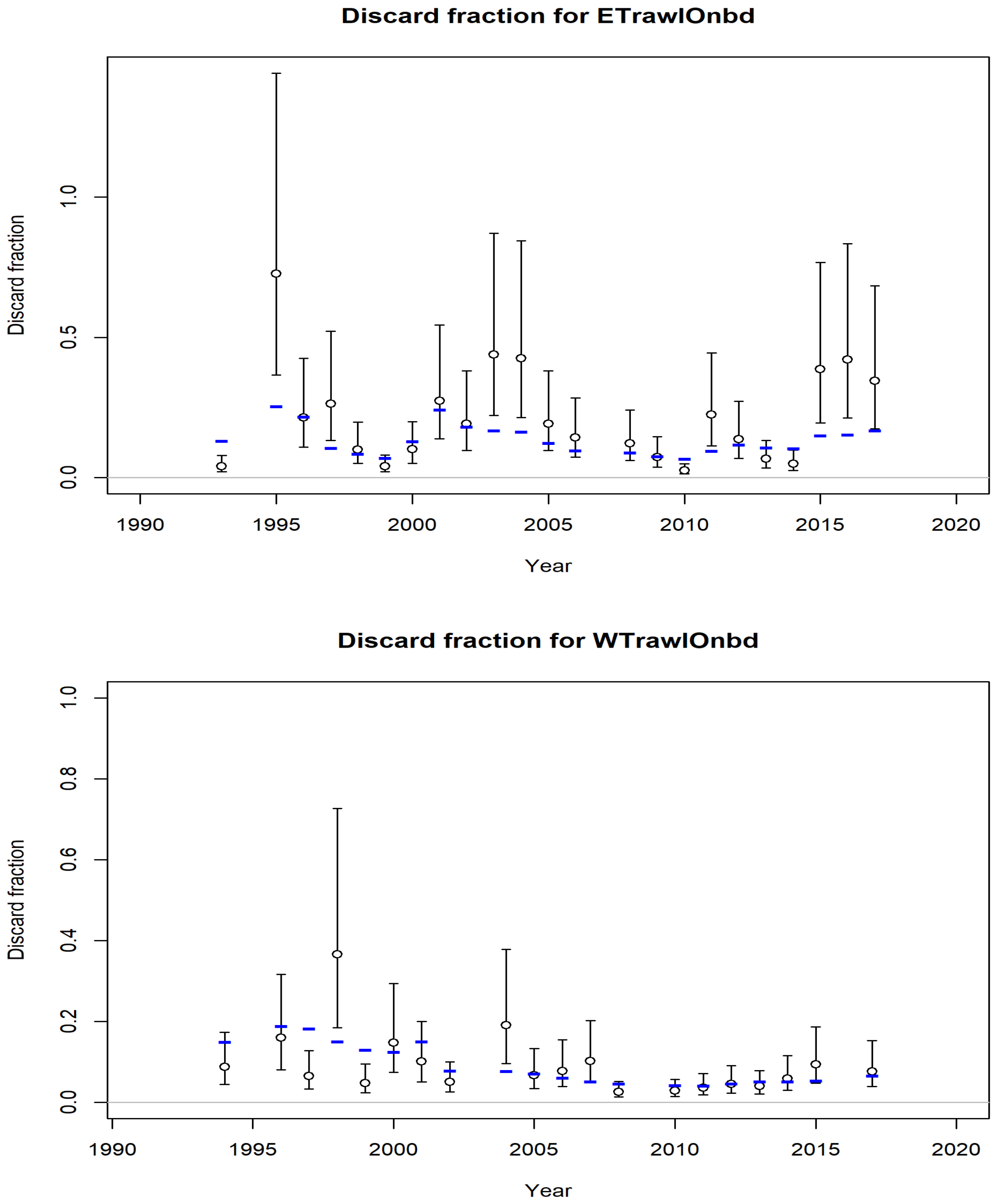


Figure 14. Observed (circles) and model-estimated (blue lines) discard estimates versus year, with approximate 95% asymptotic intervals for the Eastern trawl fleet (top) and western trawl fleet (bottom).

2.1.5 Assessment outcomes for the base case model

Figure 15 shows the relative spawning stock biomass with the limit and target reference points at 20% and 48% respectively. Stock size began to decline in the late 1980s concurrent with the increase in catches. Above average recruitment in the early 1990s (Figure 18) saw stock size increase towards the end of the 1990s even as catches reached 2000t per annum. Declines in stock size in the early 2000s are associated with catches peaking at between 3000 and 4000t and saw the stock drop below the target reference point in 2002 and 2003. Another period of above average recruitment in the late 1990s / early 2000s saw stock size increase in the mid-2000s. From 2007 – 2013 stock size declined even though catches were also declining over this period. Between 2013 and 2016 the stock has remained just above the limit reference point before increasing in 2017. This increase in stock size towards the end of the series should be treated with some caution as this is a result of the model imposed average recruitment from 2014 onwards, when recruitment is unable to be estimated reliably. As data becomes available to inform these recruitment events in future assessments, the increase in stock size from 2017 may be revised.

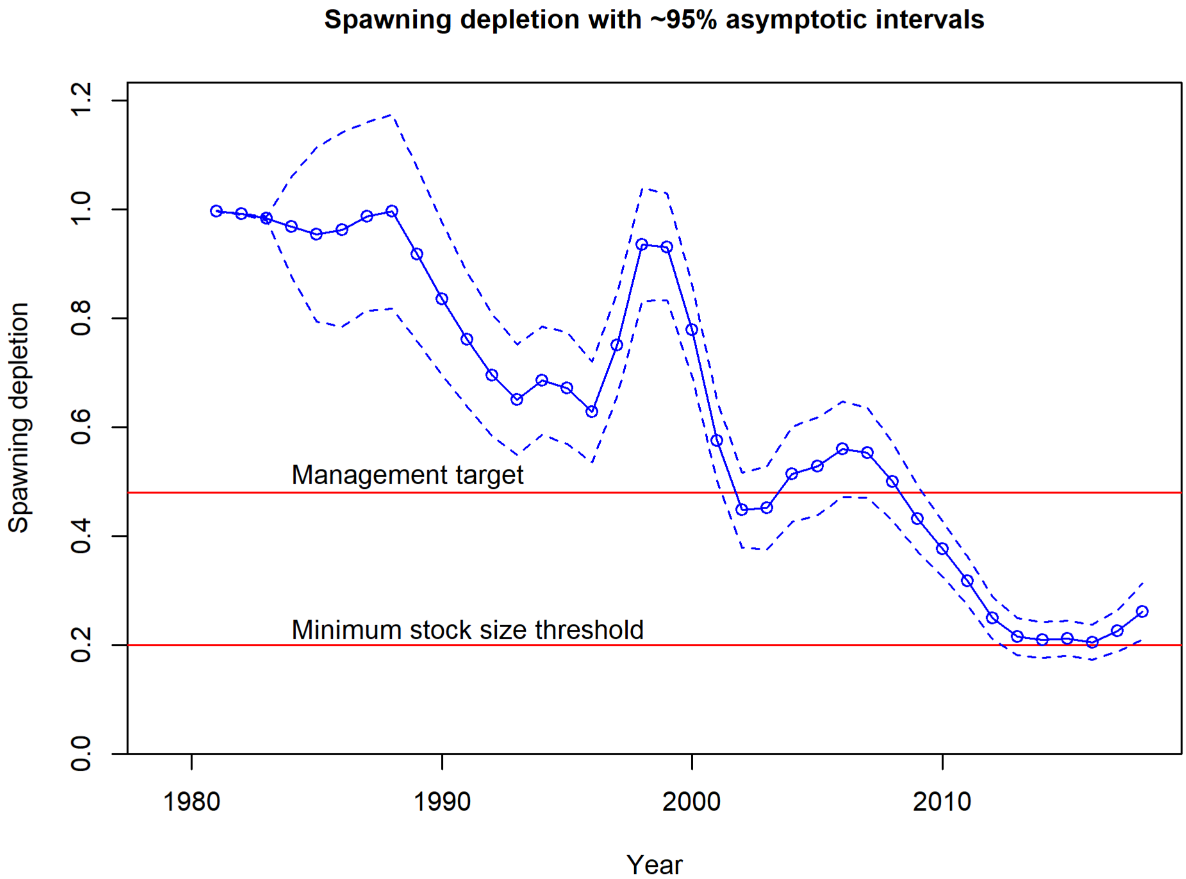


Figure 15. Time-trajectory of spawning biomass expressed as a percentage of virgin (with 95% confidence intervals) corresponding to the MPD estimates for silver warehou.

The time-trajectories of recruitment deviations are shown in Figure 16 and the bias adjustment and standard errors of recruitment deviation estimates are shown in Figure 17. Note that the last 11 estimated recruitment events have been below average. While the most recent two estimated recruitments are higher than those in preceding years, recent recruitments have been revised downwards in in subsequent assessments (Day *et al.* 2012, 2015).

The current (2019) spawning stock biomass is estimated to be 31% of unfished stock biomass (i.e. 2019 spawning biomass relative to unfished spawning biomass).

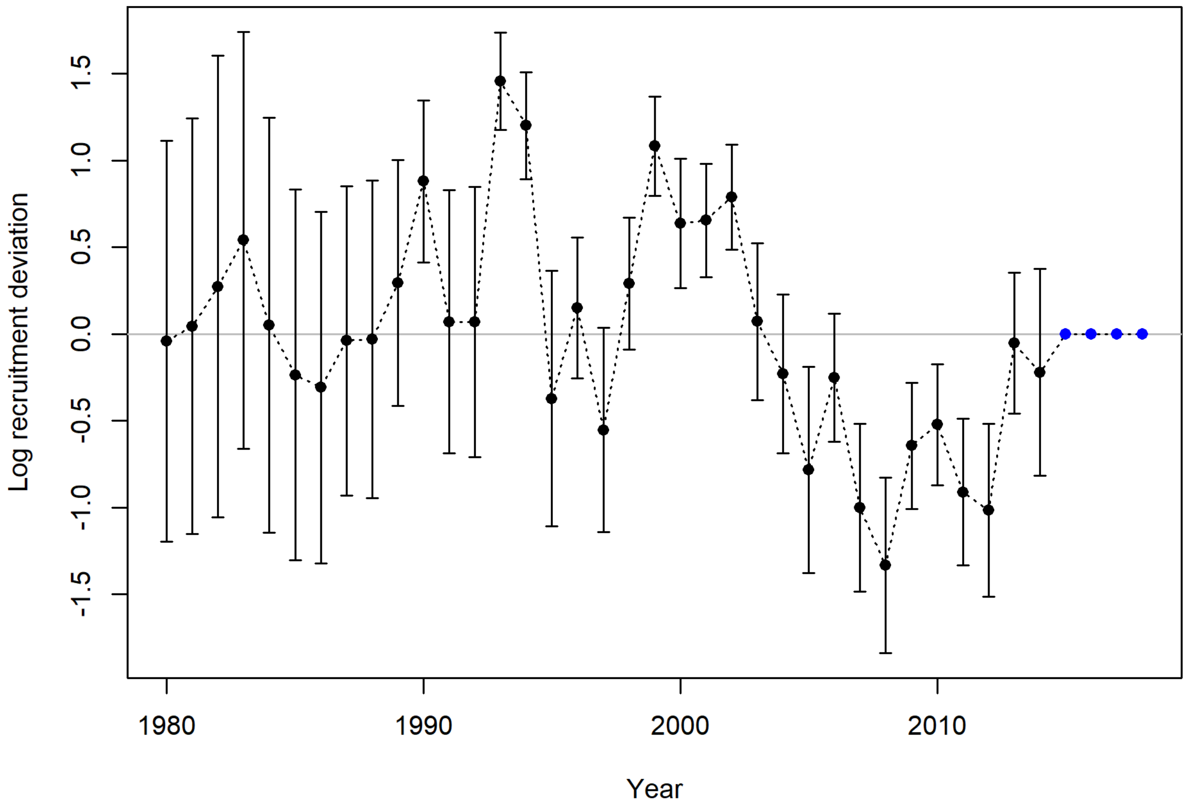


Figure 16. Recruitment estimates for the base case for silver warehou. Time trajectories of estimated log recruitment deviations, with approximate error distributions.

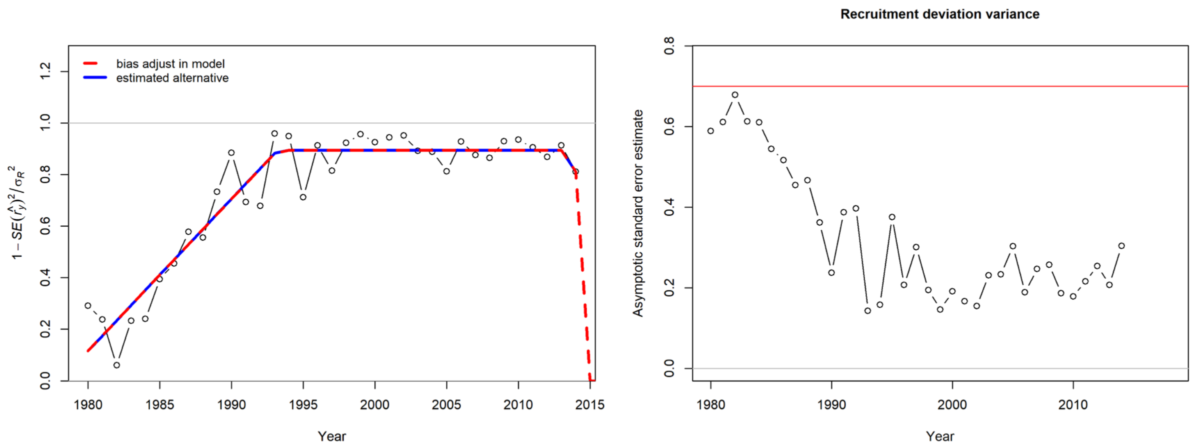


Figure 17. Bias adjustment (left) and standard errors of recruitment deviation estimates (right) for the base case for silver warehou.

2.2 Sensitivities and alternative models

Results of the sensitivity tests are shown in Table 10 and Table 11. None of the sensitivities gave relative spawning biomass estimates below the limit reference point or above the target reference point. For the fixed parameters, the results are most sensitive to the assumed value for natural mortality (*M*). However, even with *M*=0.35, the improved fits to the survey, discard and age data give an improvement to the overall likelihood of only nine units. Changing the size at 50% maturity changes the spawning biomass relative to the unfished level but has no impact on the model fit (ΔLL=0). Including the FIS results in a slightly poorer fit and a relative spawning biomass level 1% higher than the base case. While the 2015 assessment was sensitive to changing σ_R it had little effect on the 2018 assessment.

Changing the weighting on various data sources has relatively large impacts on the relative spawning biomass estimates. The likelihood cannot be compared directly in these cases, but Table 10 shows the relative differences between the different components of the total likelihood, attributable to these changes. The estimated relative spawning biomass is 38% of virgin when catches from 1998 – 2002 are doubled, 36% when the weight on the CPUE is halved and 35% when recruitment is only estimated to 2013.

Table 10. Summary of results for the base case and sensitivity tests (log-likelihood (LL) values that are comparable are in bold face). Spawning stock biomass includes both male and female biomass in the total.

Model	LL	ΔLL	SB0	SB_{2019}	SB_{2019}/SB_0	2019 RBC (t)	long term RBC (t)
base case (*M*=0.3, *h*=0.7)	**625**	-	18949	5930	0.31	942	1773
FIS	627	2	18996	6021	0.32	-	-
M=0.25	**636**	11	19368	5127	0.26	-	-
M=0.35	**616**	-9	20290	7340	0.36	-	-
h=0.65	**625**	0	19690	5731	0.29	-	-
h=0.85	**625**	0	18438	6120	0.33	-	-
50% maturity at 34cm	**625**	0	20652	7170	0.35	-	-
50% maturity at 40cm	**625**	0	16670	4545	0.27	-	-
σ_R = 0.6	**626**	1	18222	5999	0.33	-	-
σ_R = 0.8	**625**	0	19908	5919	0.3	-	-
est. recruitment to 2013	626	1	19058	6682	0.35	-	-
est. recruitment to 2015	625	0	19038	5920	0.31	-	-
double weight on CPUE	550	-75	18848	5404	0.29	-	-
halve weight on CPUE	657	32	19426	6910	0.36	-	-
double weight on lengths	846	221	18658	6180	0.33	-	-
halve weight on lengths	507	-118	19562	6031	0.31	-	-
double weight on age	921	296	19376	5922	0.31	-	-
halve weight on age	471	-154	18667	5969	0.32	-	-
double catch 1998-2002	643	18	26990	10390	0.38	-	-

Table 11. Summary of likelihood components for the base case and sensitivity tests. Likelihood components are unweighted and all cases below the primary base case are shown as differences from the base case. A negative value either in the total or individual components of likelihood indicates an improvement in fit compared to the primary base case. A positive value indicates deterioration in the fit.

Model	Likelihood TOTAL	Δ LL	Survey	Discard	Length	Age	Recruitment
base case (*M*=0.3, *h*=0.7)	625.08	0	-68.66	23.69	362.17	302.11	5.39
FIS	626.76	1.68	1.45	-0.07	0.87	-0.48	-0.09
M=0.25	635.77	10.69	4.61	1.07	2.09	2.45	0.34
M=0.35	616.41	-8.67	-4.07	-0.99	-2	-1.78	0.33
h=0.65	624.77	-0.31	-0.33	0.62	0.18	-0.11	-0.66
h=0.85	625.46	0.38	0.27	-0.51	-0.07	0.09	0.6
50% maturity at 34cm	625.04	-0.04	0	-0.03	-0.02	0.01	0.01
50% maturity at 40cm	625.03	-0.05	0.03	0.05	-0.07	0.02	-0.07
σ_R = 0.6	626.48	1.4	0.9	0.32	-0.12	-0.06	0.36
σ_R = 0.8	624.91	-0.17	-0.53	-0.26	0.08	0.11	0.44
est. recruitment to 2011	626.39	1.31	1.73	-1.79	-0.5	1.64	0.23
est. recruitment to 2013	624.85	-0.23	-0.01	0.03	-0.02	0.01	-0.22
double weight on CPUE	629.56	4.48	-10.47	5.13	9.93	-2.35	2.28
halve weight on CPUE	627.95	2.87	10.6	-2.52	-7.97	4.34	-1.6
double weight on lengths	565.29	-59.80	10.81	2.88	-81.31	8.44	-0.67
halve weight on lengths	761.02	135.94	-5.19	-1.69	146.73	-4.12	0.28
double weight on age	629.59	4.505	-3.22	5.35	13.24	-10.72	-0.1
halve weight on age	629.50	4.42	4.34	-4.47	-10.73	14.97	0.28
double catch 1998-2002	643.17	18.09	18.06	-1.13	0.46	0.91	-0.34

2.3 Application of the harvest control rules in 2018

An estimate of the catch for the 2018 calendar year is needed to run the model forward to calculate the 2019 spawning biomass and percentage of the unfished spawning biomass. Given that recent TACs have been under-caught and catches have been stable in the most recent four years, the catch in 2018 is assumed to equal that of 2017 (348.1t). The assessment estimates that percentage of the unfished spawning biomass was just above the 20% limit reference point between 2013 and 2016 with the lower 95% asymptotic confidence intervals being below the limit reference point between 2013 and 2017 (Figure 18).

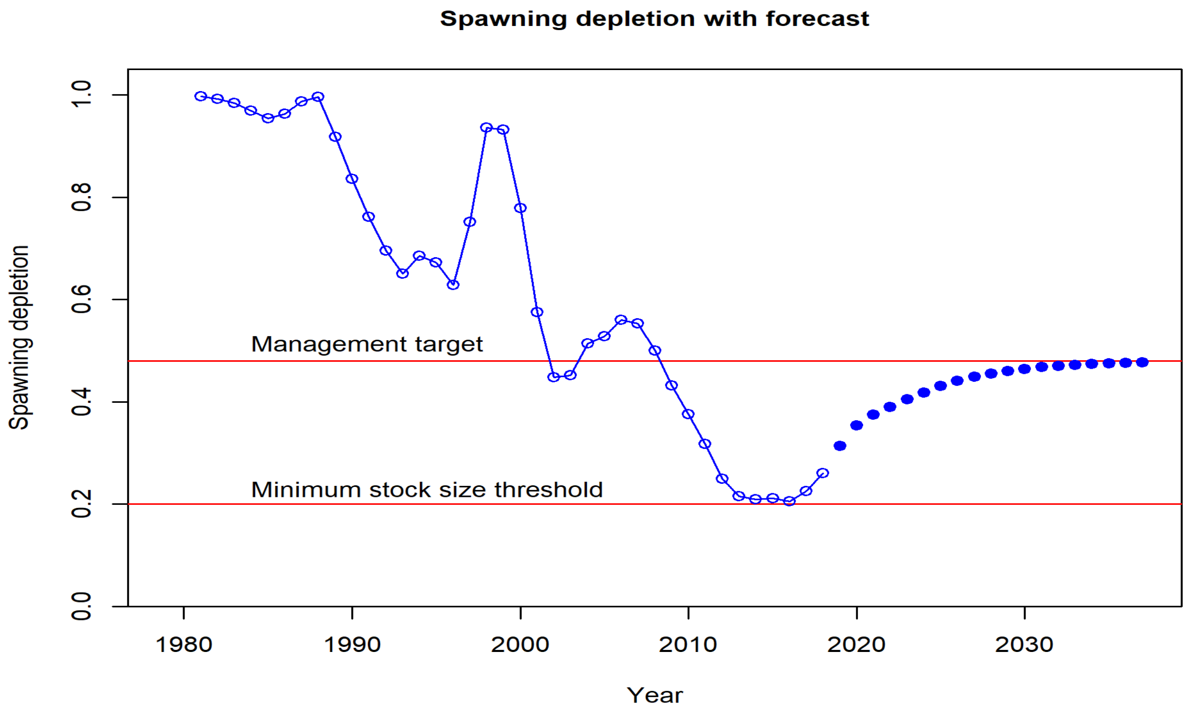


Figure 18. The projection of relative spawning biomass under the 20:35:48 rule for silver warehou.

The percentage of the unfished spawning biomass in 2019 under the base-case parameterisation is estimated to be 31.3%.

An application of the Tier 1 harvest control rule with a target spawning biomass of 48% of unfished levels leads to the 2019 and long-term RBCs of 942t and 1,772t (Table 10). An example of the time-series of RBCs and corresponding spawning biomass corresponding to the calculated RBCs for the 20:35:48 harvest control rule is shown in Figure 18. Table 12 shows the annual RBCs and percentage of the unfished spawning biomass estimates under the 20:35:48 harvest control rule.

Model estimated discard rates for 2019-2021 are required for calculation of the TAC from the RBC, and these can be obtained from Stock Synthesis output files. Under the assumption of average recruitment from 2015 onwards and assuming that the RBC is caught in full each year, the estimated discard mass for these years follow: 88t in 2019; 122t in 2020; and 126t in 2021 (Table 12).

Table 12. Summary of the annual percentage of the unfished spawning biomass, RBCs and estimated discard mass for the base case under the 20:35:48 harvest control rule.

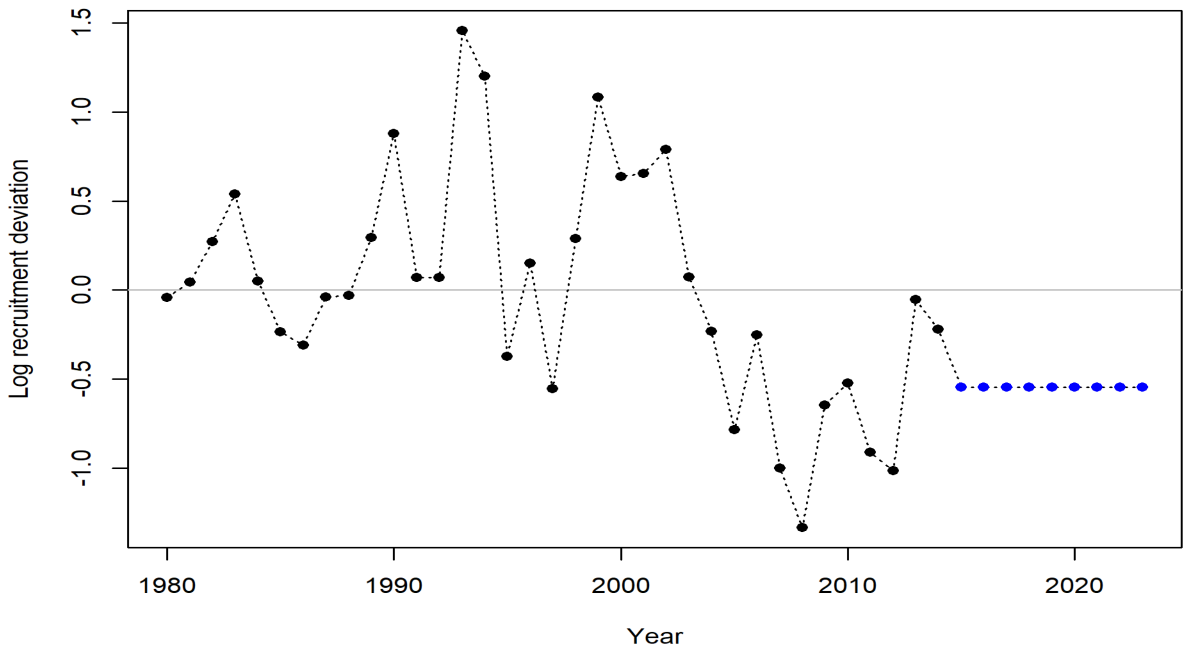
Year	Percentage $SSB_{current}/SSB_0$	RBC (t)	Discard mass (t)
2019	31.3	942.1	88.1
2020	35.4	1352.8	121.9
2021	37.4	1419.6	125.8
2022	39.0	1477.0	129.5
2023	40.4	1528.4	132.6

2.4 Scenarios with low recruitment for 2015-2023

2.4.1 Poor and very poor recruitment scenarios

To explore the possible impact of continued poor recruitment, two additional recruitment scenarios were examined where recruitment was assumed to be poor in the period 2015-2023. In this case, the standard forward projections, assuming average recruitment, could produce RBCs that, if caught, could result in a lower spawning biomass than the target level. The first recruitment scenario, referred to as “poor recruitment” took the mean of the log recruitment deviations in the base case estimated from 2010-2014, giving a value of -0.545. This represented a recent period of five poor recruitment events. The second recruitment scenario, referred to as “very poor recruitment” took the mean of the log recruitment deviation from the worst three of these years, 2010-2012, giving a value of -0.817. The recruitment estimates from the poor and very poor recruitment scenarios are shown in Figure 19.

The same scenarios were explored for the 2015 assessment (Day *et al.* 2015) with the mean log recruitment deviations from the last five estimated recruitments was -0.576 while the mean of the lowest three of the last five estimated recruitments was -0.799.



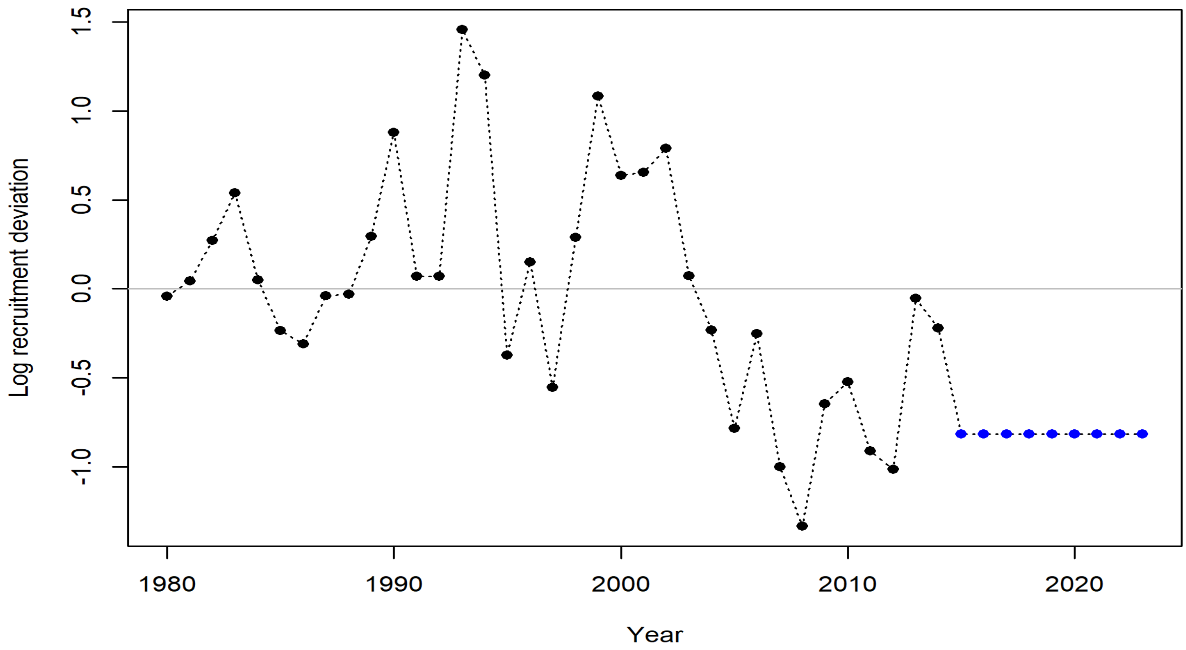


Figure 19. Time trajectories of log recruitment deviations estimates for the scenario with poor recruitment (top) and very poor recruitment (bottom).

2.4.2 Fixed catch projection to 2023

For the two poor recruitment scenarios, the dynamics were projected forward for five additional years, initially with a fixed catch level, set at the 2017 catch, 348t. Note that with discards being estimated, there are additional removals, and while the forecast landed catch is set to 348t, the actual total catch is somewhat higher due to the inclusion of discards. The 2017 catch has been chosen for these scenarios rather than the RBC because the RBC has not been caught for a number of years (Table 1). Scenarios and percentages of the unfished spawning biomass are shown in Figure 20, Table 13 and Table 14.

At its November 2018 meeting, SERAG agreed to recommend a TAC for silver warehou based on the assumption that recruitment will remain below average in the next few years. SERAG chose to assume that recruitment would remain at the mean of the last five years of estimated recruitments in the base case model (2010 – 2014). SERAG requested additional constant catch projections for the poor recruitment scenario of between 400 t and 750 t as well as the RBCs from the base case model which assumes average recruitment (942 t in 2019).

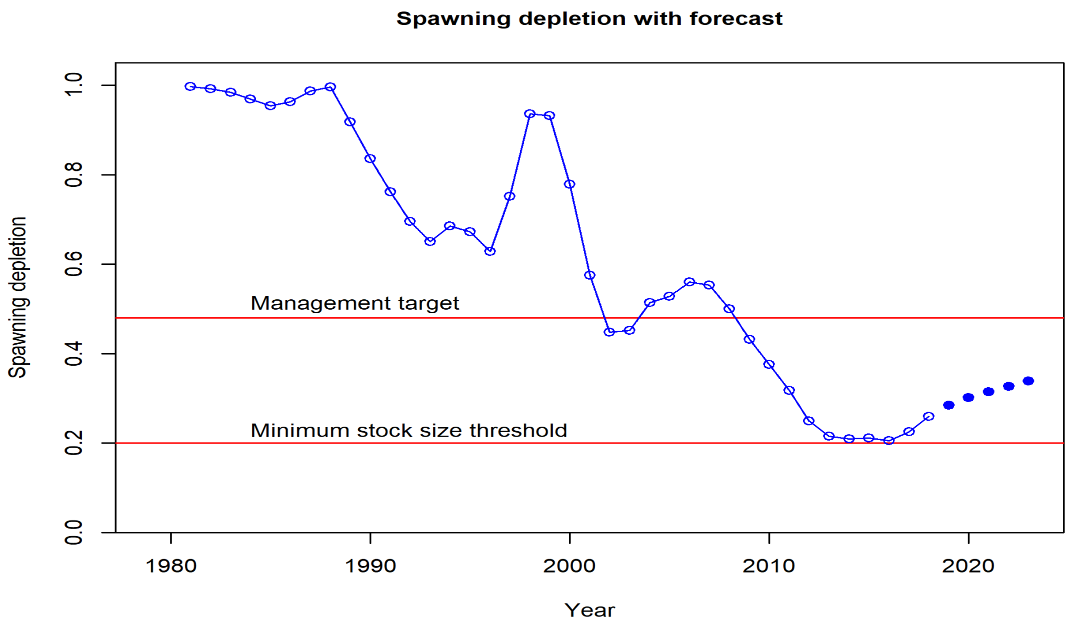
Under the poor recruitment scenario, constant annual catches of 750 t or more led to the estimated spawning biomass declining under the low recruitment scenario (Table 13). For constant annual catches between 348 t and 600 t spawning biomass is predicted to increase, albeit more slowly than the base case which assumes average recruitment (Table 13). In the very poor recruitment scenario with a constant annual catch of 348 t the estimated spawning biomass remains around 27% between 2019 and 2023 (Table 14).

Table 13. Estimated percentage of virgin spawning biomass assuming poor recruitment from 2015-2023 from a series of fixed landed catches between 348t and the catches from the base case model assuming average recruitment (denoted with *). Estimates of total and discarded catch are provided for each scenario.

Catch scenario	Year	Percentage $SSB_{current}/SSB_0$	Total catch (t)	Discarded catch (t)
348	2019	28.4	376	28
348	2020	30.1	375	27
348	2021	31.4	375	27
348	2022	32.6	374	26
348	2023	33.9	374	26
400	2019	28.4	432	32
400	2020	29.9	431	31
400	2021	31.0	431	31
400	2022	32.0	431	31
400	2023	33.1	430	30
450	2019	28.4	486	36
450	2020	29.6	486	36
450	2021	30.5	485	35
450	2022	31.4	485	35
450	2023	32.3	484	34
500	2019	28.4	540	40
500	2020	29.4	540	40
500	2021	30.1	539	39
500	2022	30.7	539	39
500	2023	31.5	539	39
550	2019	28.4	594	44
550	2020	29.2	594	44
550	2021	29.6	594	44
550	2022	30.1	594	44
550	2023	30.7	593	43
600	2019	28.4	649	49
600	2020	29.0	648	48
600	2021	29.2	648	48
600	2022	29.5	648	48
600	2023	29.9	648	48
750	2019	28.4	811	61
750	2020	28.3	811	61
750	2021	27.9	812	62
750	2022	27.6	812	62
750	2023	27.5	813	63
854*	2019	28.4	924	70
1231*	2020	27.8	1333	102
1294*	2021	25.3	1408	114
1348*	2022	22.7	1474	127
1396*	2023	20.4	1535	139

Table 14. Estimated percentage of virgin spawning biomass assuming very poor recruitment from 2015-2023 assuming a fixed annual catch of 348t. Estimates of total and discarded catch are provided.

Catch scenario	Year	Percentage $SSB_{current}/SSB_0$	Total catch (t)	Discarded catch (t)
348	2019	27.5	373	25
348	2020	27.6	373	24
348	2021	27.4	373	24
348	2022	27.2	373	25
348	2023	27.2	373	25



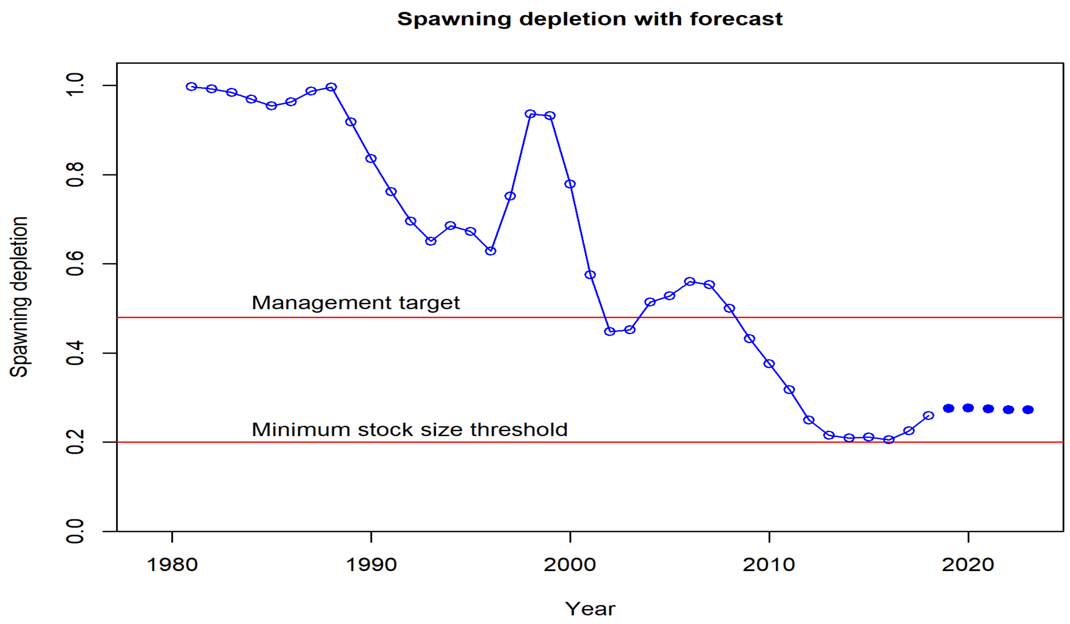


Figure 20. The poor (top) and very poor (bottom) recruitment scenario projections of relative spawning biomass with fixed catch of 348t (2017 catch).

2.4.3 Retrospective analysis

Given the changes to the silver warehou assessment since 2012, a retrospective analysis was undertaken to identify whether the downward revision of recent recruitments and upward trends in the percentage of the unfished spawning biomass seen in previous assessments (Day *et al.* 2012, 2015) was present with the 2018 assessment structure, data and tuning methods. For the 2016 and 2014 assessment scenarios, an increase in estimated percentage of the unfished spawning biomass in the final two or three years of the assessment is observed (Figure 21), however, this pattern was not present in the 2012 assessment scenario. It is interesting to note that the assessment appears to have shifted to a lower productivity state between the 2014 and 2016 scenarios. Figure 22 shows a similar pattern with the estimated recruitment deviations, with recruitments from the 2014 and 2016 scenarios being revised downwards in subsequent assessments, while recruitments from the 2012 scenario changed little in subsequent assessments.

This analysis corroborates the pattern of overly optimistic recent recruitments and trends in the percentage of the unfished spawning biomass seen in previous assessments of silver warehou (Day *et al.* 2012, 2015) under the 2018 assessment structure, data and tuning methods.

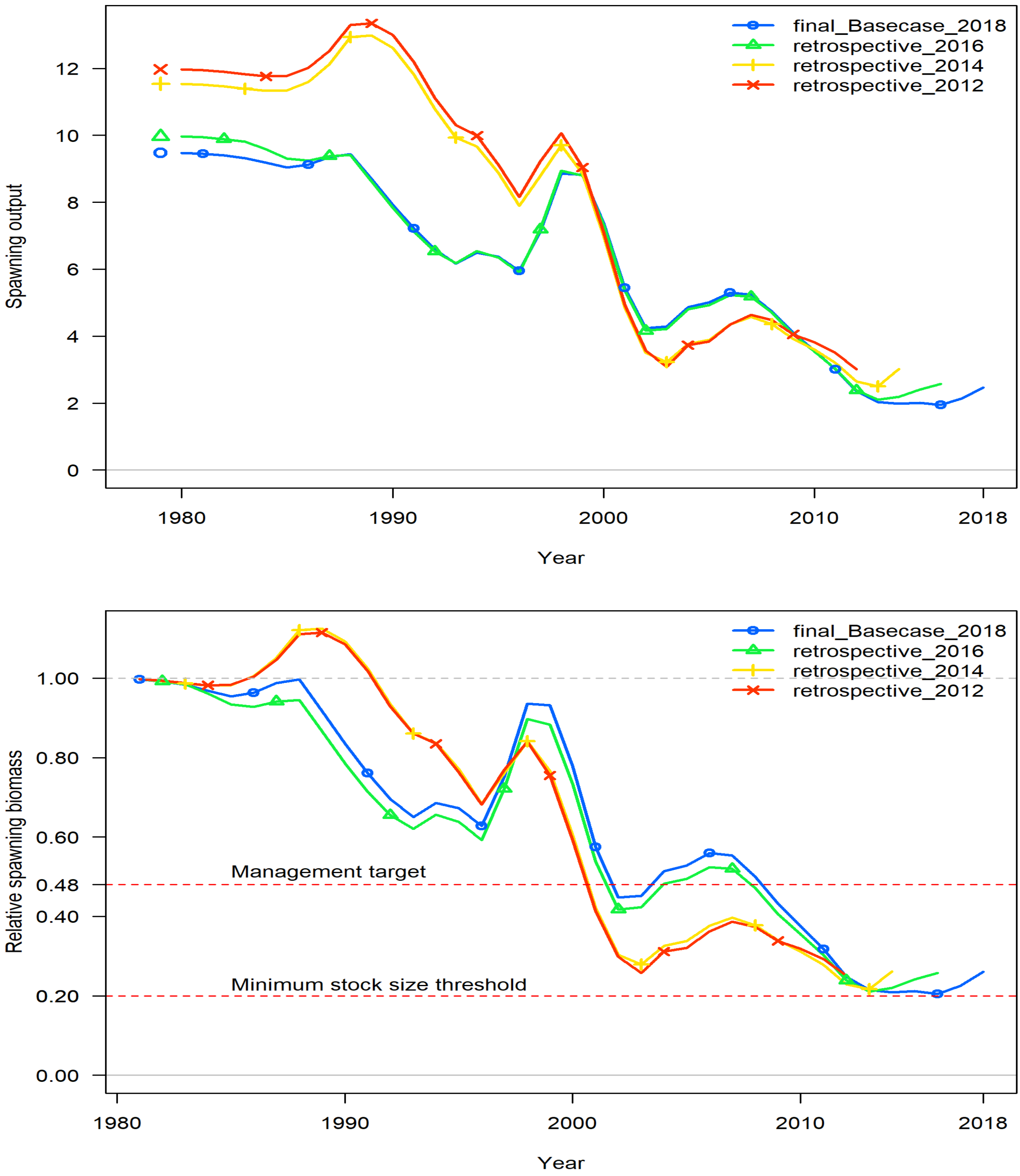


Figure 21. Retrospective analysis of absolute (top) and relative (bottom) spawning biomass. Two years of data were removed from the base case and the model retuned to produce the assessments for 2016, 2014 and 2012 using the same model structure at the 2018 base case.

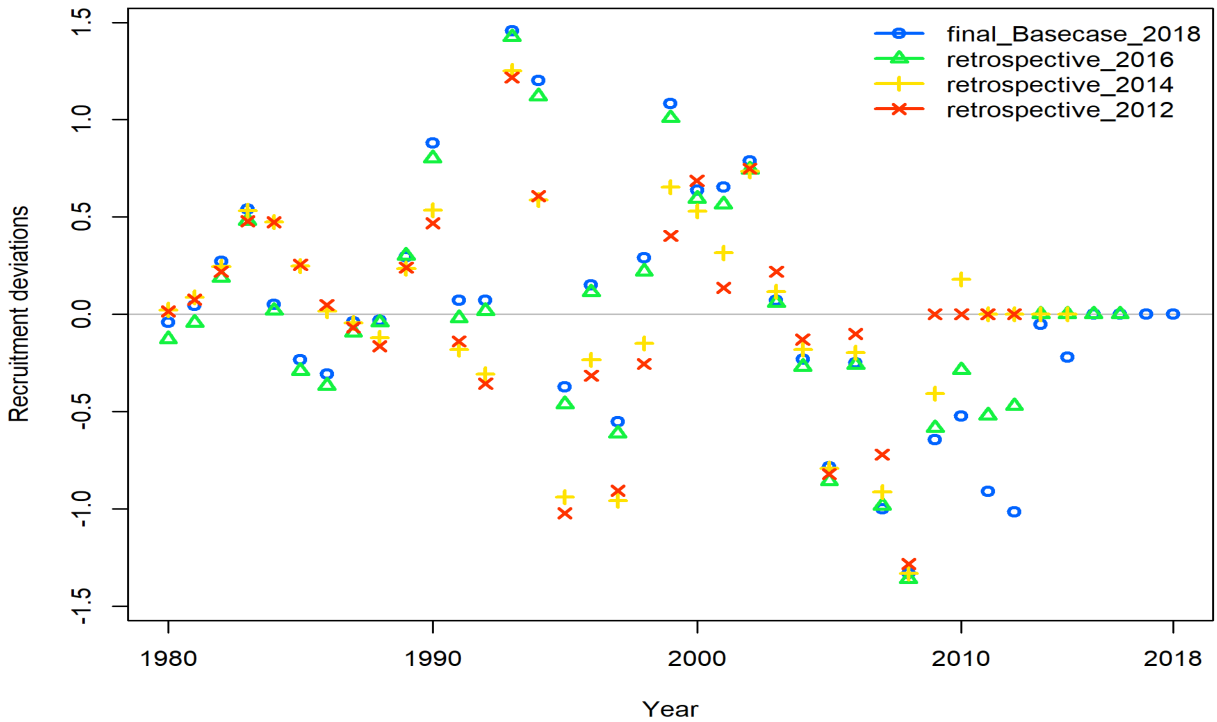


Figure 22. Retrospective analysis of estimated recruitment deviations. Two years of data were removed from the base case and the model retuned to produce the assessments for 2016, 2014 and 2012 using the same model structure at the 2018 base case.

2.4.4 MCMC analysis for the base case

All seven MCMC chains passed standard diagnostic tests (Appendix B2). There was very little variability among the seven MCMC chains for time series of estimated percentage of spawning biomass (Figure 23). Estimated recruitment, recruitment deviations and growth parameters similarly showed little variability among the seven MCMC chains (Appendix B1). The Bayesian implementation is almost identical to the Maximum Likelihood implementation (Appendix B3). The only discernible difference was the Maximum Likelihood estimates of spawning biomass prior to 2000 are lower than the MCMC estimates (Figure 24). This results in the estimated percentage of virgin spawning biomass from the MCMC in 2019 of 30.4% being slightly lower than the MLE estimate of 31.3% (Table 15).

Credible intervals from the MCMC analysis show that the probability that the spawning biomass was below the limit reference point was greater than 20% between 2013 and 2016 (Table 15). In 2017 the probability the spawning biomass was below the limit reference point was 8% and in 2018 and 2019 the probability the spawning biomass was below the limit reference point is <1%.

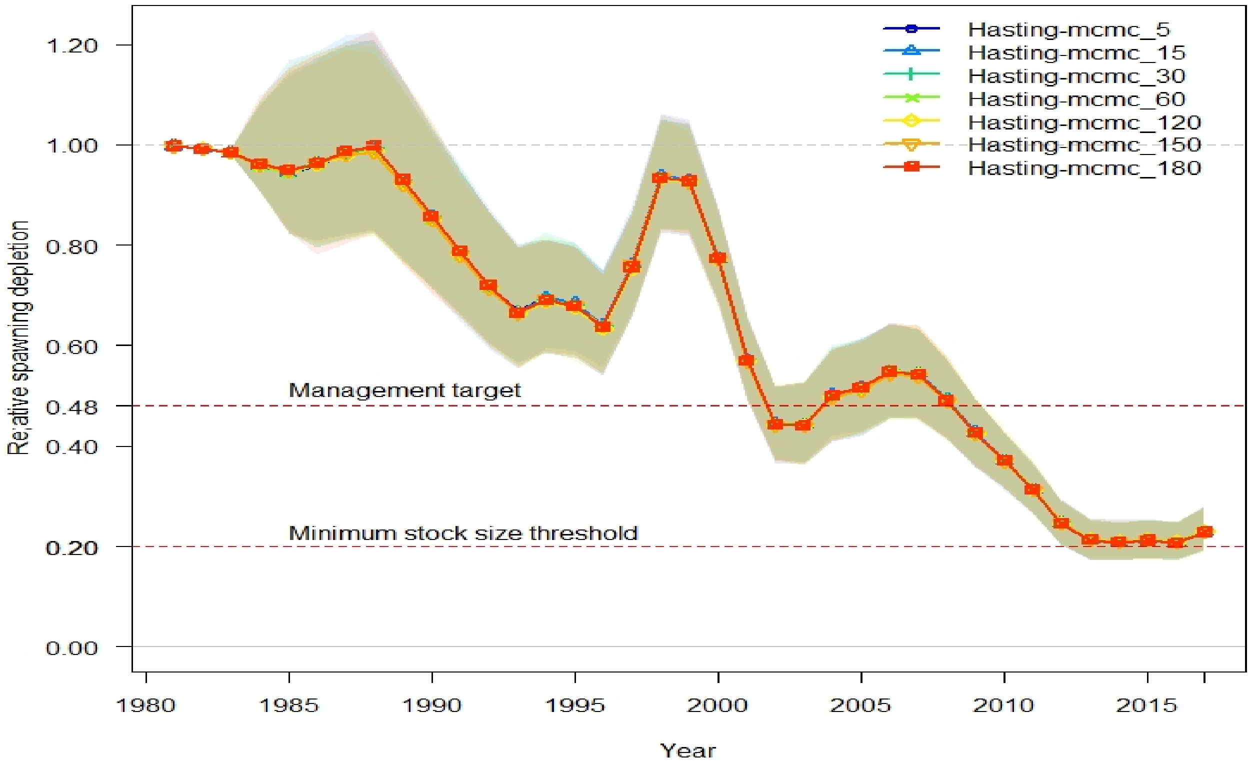


Figure 23. Time series of estimated spawning biomass relative to virgin levels from seven MCMC chains of the base case model. Shaded area represents 95% credible interval. Note estimates and credible intervals from all chains overlap.

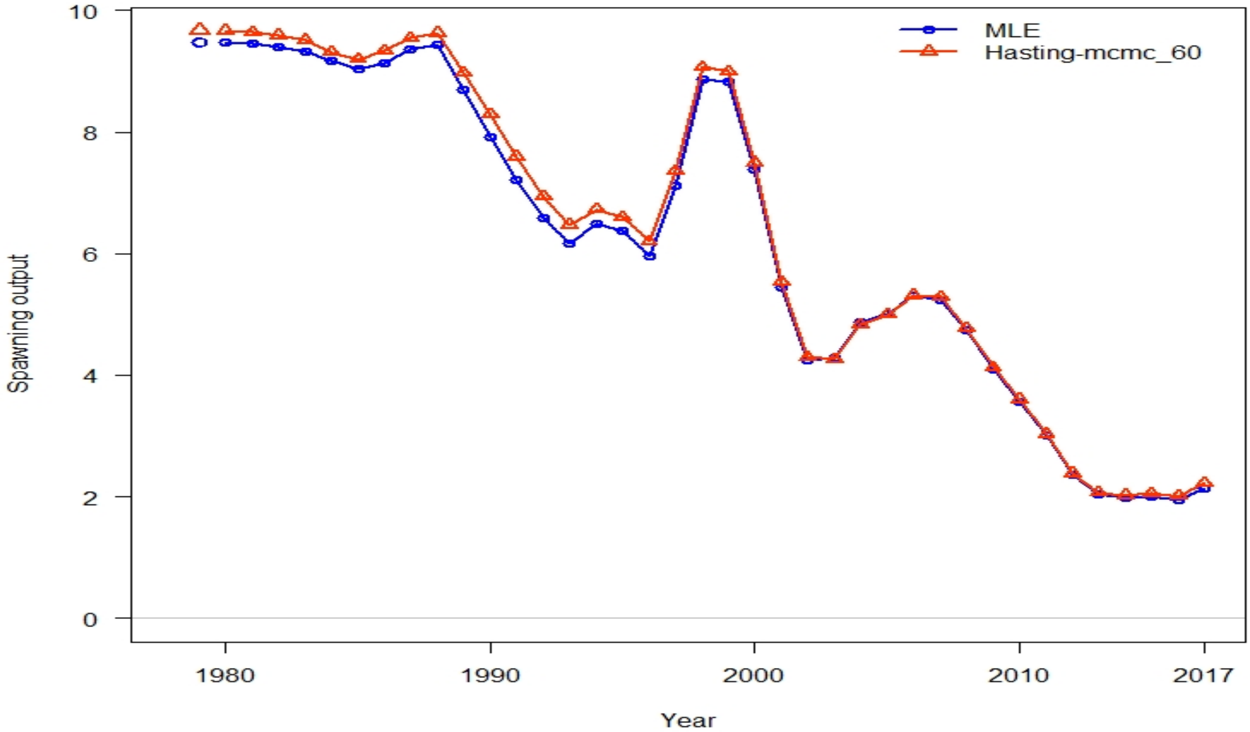


Figure 24. Time series of absolute spawning biomass estimates from the maximum likelihood estimate (MLE) and one MCMC chain of the base case model.

Table 15. Estimated percentage of virgin spawning biomass and percentage chance of being below the limit reference point from MCMC.

Year	Percent $SSB_{current}/SSB_0$	Percent chance below 20%
2012	24.6	2.3
2013	21.3	26.0
2014	20.9	32.4
2015	21.3	24.8
2016	20.8	32.2
2017	23.1	8.0
2018	26.5	0.3
2019	30.4	<0.1

2.5 Future work and unresolved issues

There is still the need to investigate the impact of separating the discarded catch estimates into eastern and western trawl fleets which caused difficulties in convergence. Difficulties in tuning were observed for the preliminary base case model and the likelihood profile for natural mortality estimated *M*=0.5 (Burch *et al.* 2018a), which suggests some inconsistencies between the data and assumed fixed parameters. Additionally, the question of discarding from factory trawlers could be investigated further to determine whether discarded silver warehou catches from factory trawlers were recorded in the CDR data.

The differences in the length composition data between onboard and port samples, particularly in the east, may indicate that the east / west split in the assessment may not be capturing all of the depth related variability in population structure. If depth related variability in length does occur in the east then a depth structure model may need to be considered and the utility of port sampling in the east should be examined because depth of fishing is not available for port samples that are aggregated over many shots.

Potential problems with the CPUE series that provide abundance indices have been identified by Sporcic and Haddon (2018a). While the base case model fits to the western trawl CPUE are good, particularly in recent years, the fits to the eastern trawl CPUE are poor and show signs of autocorrelation. An examination of the CPUE for evidence of changes in targeting practices is also recommended. An additional sensitivity of including FIS length-composition data and attempting to estimate selectivity for the FIS fleets would be useful.

This study confirmed that the retrospective pattern of optimistic recent recruitments being revised downwards in subsequent assessments (Day et al. 2012, Day et al. 2015) is still present with the 2018 assessment structure and is a serious concern. As this retrospective pattern may overestimate the current spawning biomass and hence stock status, understanding why the retrospective pattern occurs and correcting it if possible is urgently needed.

3 Conclusion

This document presents an updated assessment of silver warehou (*Seriolella punctata*) in the SESSF using data up to 31 December 2017. A full stock assessment for silver warehou was last performed in 2015 by Day *et al.* (2015) using the stock assessment package Stock Synthesis version SS-V3.24U (Methot 2015). Changes from the 2015 assessment include: (a) migration to the latest version of Stock Synthesis (SS-V3.30.12, Methot *et al.* 2018), (b) updates of all catch, discard, length, age and catch rate data and the last year of estimation of recruitment (2014), three years prior to the last year of data (2017), (c) including silver warehou catches from the GHAT and the SPF (d) separating the discard series separated into east and west components and incorporating factory trawler discard information where available, (e) removal of FIS abundance estimates from the preliminary base case and (i) adopting the new tuning methods.

Results show reasonable fits to the CPUE abundance index for the western trawl fleet, however, fits to the eastern trawl fleet are poor prior to 2008. There are differences in the length distributions from onboard and port sampling in both the east and the west, resulting in poor fits to the aggregated length distributions for the eastern trawl fleet. In the west, the fits to the aggregated length distributions were reasonable. The overall fits to the retained length and conditional age-at-length data are reasonable, although there are poor fits in some years. Fits to the discard length data are poor, particularly in the west. Inclusion of the fishery independent survey (FIS) data as a model sensitivity has little impact on either the trends in spawning stock biomass or the estimated percentage of the unfished spawning biomass.

The assessment fits to the most recent three CPUE data points in the east and two data points in the west suggest that the model may again be overly optimistic at the end of the time series (Day *et al.* 2015). This pattern is further highlighted by the retrospective analysis which shows increases in the estimated percentage of the unfished spawning biomass in the last few years of the 2014 and 2016 assessment scenarios are not realised in the following assessment scenario two years later. Given that the current assessment estimates that percentage of the unfished spawning biomass was only just above the 20% limit reference point between 2013 and 2016, with the lower 95% asymptotic confidence intervals being below the limit reference point (LRP) between 2013 and 2017 there is a possibility the stock is currently below the LRP.

Since the 2015 assessment the stock has seen a continued decline in CPUE, although catches have been stable since 2014 at between 350 and 400t. The last 11 years of estimated recruitment are all below average suggesting that relying on average recruitment for the stock to recover may be overly optimistic. Poor future recruitment scenarios illustrate the potential dangers to the stock if the calculated RBC is actually caught, although these impacts are reduced if the current low catch levels are maintained. This sustained period of below average estimated recruitments may be indicative of a regime shift in productivity for this stock.

Given the changes to the assessment structure, data and tuning methods since the 2012 assessment, a retrospective analysis was undertaken to determine whether the pattern of optimistic recent recruitments that have been revised downwards in subsequent assessments was still present with the 2018 assessment structure. Increases in recruitment and spawning biomass in the most recent years from the 2014 and 2016 assessment scenarios were revised downwards in subsequent assessments. This suggests that the increase in spawning biomass seen in the most recent years of 2018 assessment may be overly optimistic and that the percentage of the unfished spawning biomass may currently be around the limit reference point.

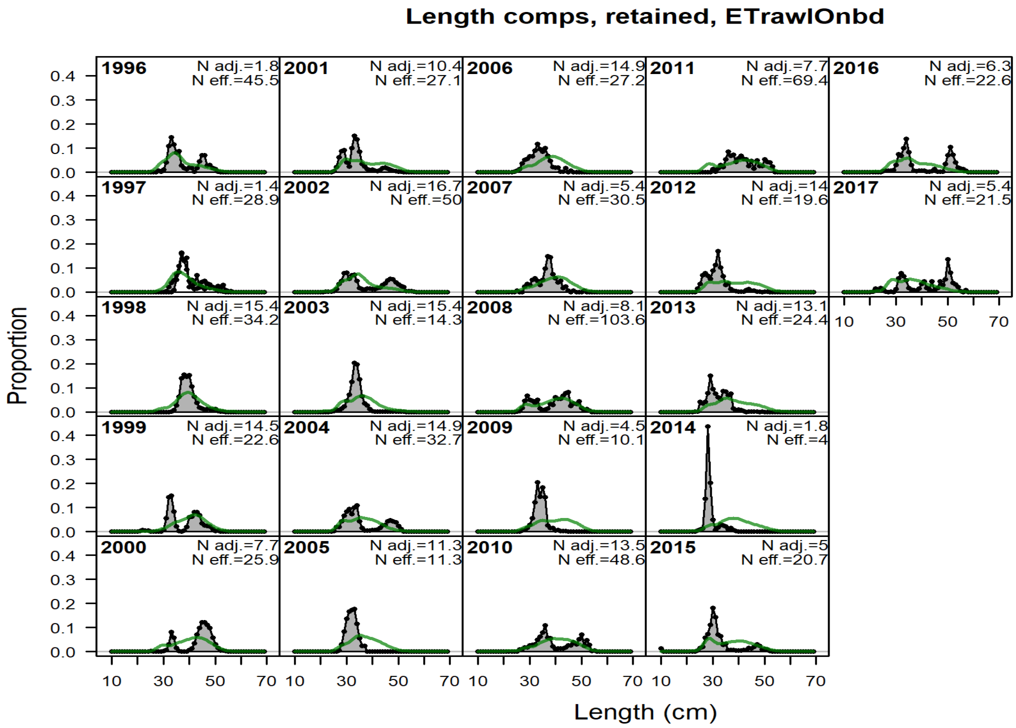
This assessment estimates that the projected 2019 spawning stock biomass will be 31% of virgin stock biomass. The RBC from the base case model for 2019 is 942t for the 20:35:48 harvest control rule, with a long-term yield of 1,773t. In comparison, the 2015 assessment estimated the 2016 percentage of the unfished spawning biomass to be 40%, with corresponding RBCs of 1,958t, with a long-term yield of 2,281t. However, these scenarios assume recruitment will return to average levels. Low and very low recruitment scenarios suggest that if current landed catches are maintained at around 350t then the stock is likely to remain above the LRP.

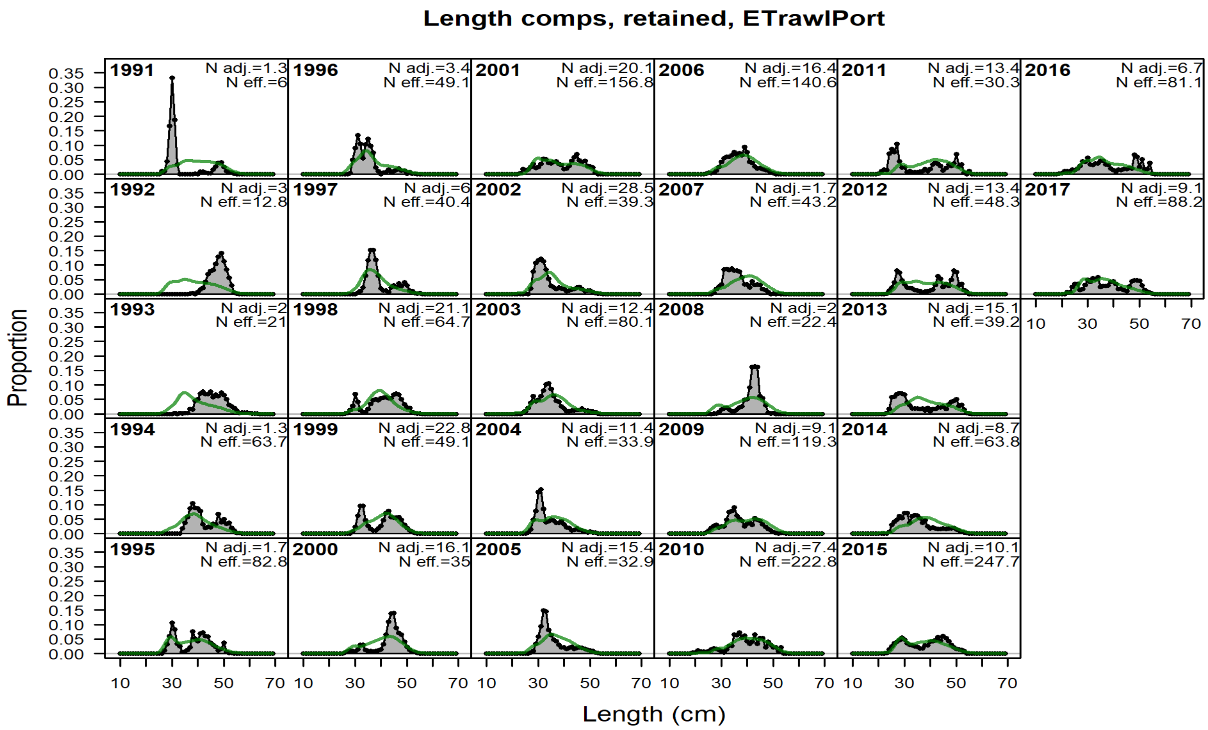
A Bayesian assessment was undertaken because the base case assessment showed that the maximum likelihood estimate of spawning biomass was near the limit reference point of 20% of its unfished level between 2013 and 2016, with the lower 95th percent asymptotic confidence intervals being below the limit reference point in those years. The probability that the spawning biomass was below the limit reference point was greater than 20% between 2013 and 2016. In 2017 the probability the spawning biomass was below the limit reference point was 8% and in 2018 and 2019 the probability the spawning biomass was below the limit reference point is <1%.

At its November 2018 meeting, SERAG agreed to recommend a TAC for silver warehou based on the assumption that recruitment will remain below average in the next few years. SERAG chose to assume that recruitment would remain at the mean of the last five years of estimated recruitments in the base case model (2010 – 2014). Projections assuming this low recruitment were run for scenarios of constant landed catch that were between the catch in the most recent year for which data is available (348 t) and the RBCs from the base case model which assumes average recruitment (942 t in 2019). Scenarios with constant annual catches of 750 t or more led to the estimated spawning biomass declining under the low recruitment scenario. Under the low recruitment scenario with constant annual catches between 348 t and 600 t spawning biomass is predicted to increase, albeit more slowly than the base case which assumes average recruitment.

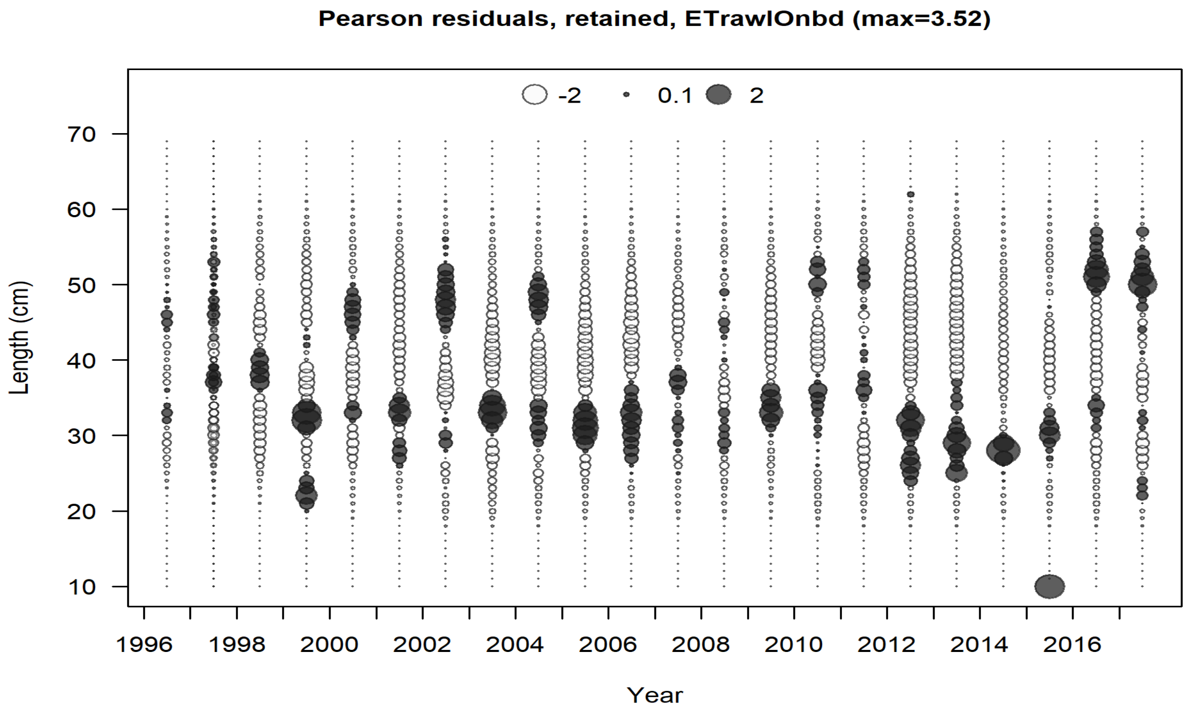
Appendix A Base case fits

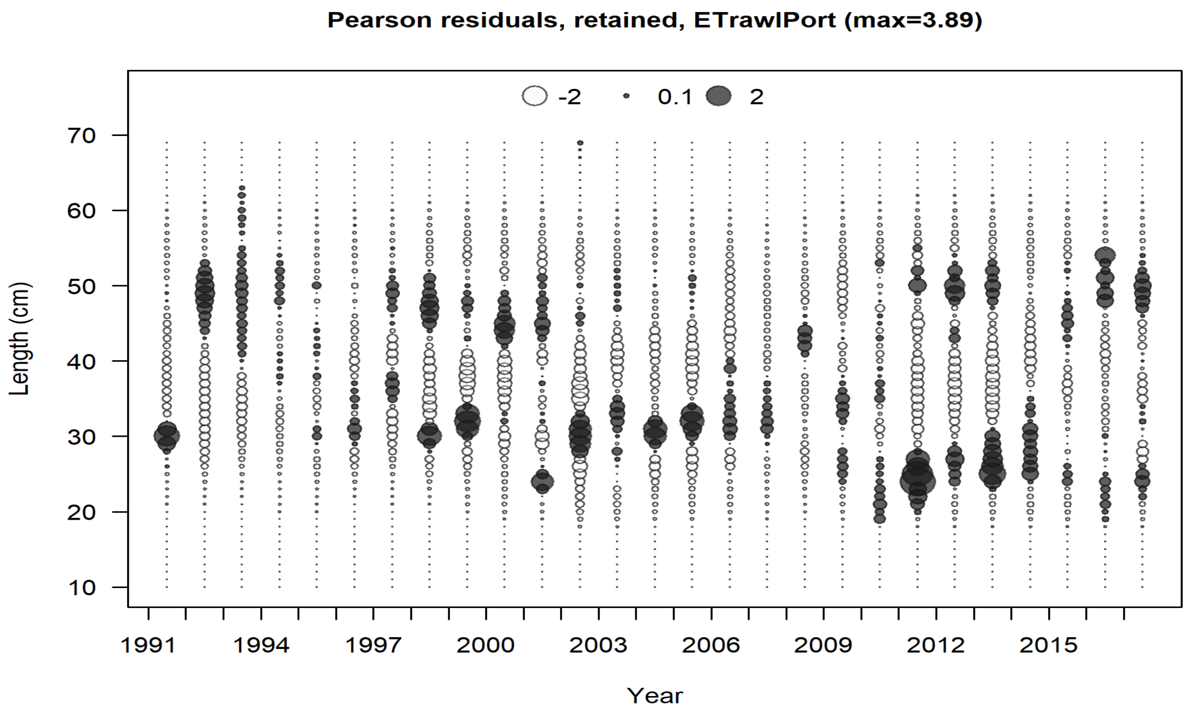
A.1 Length fits



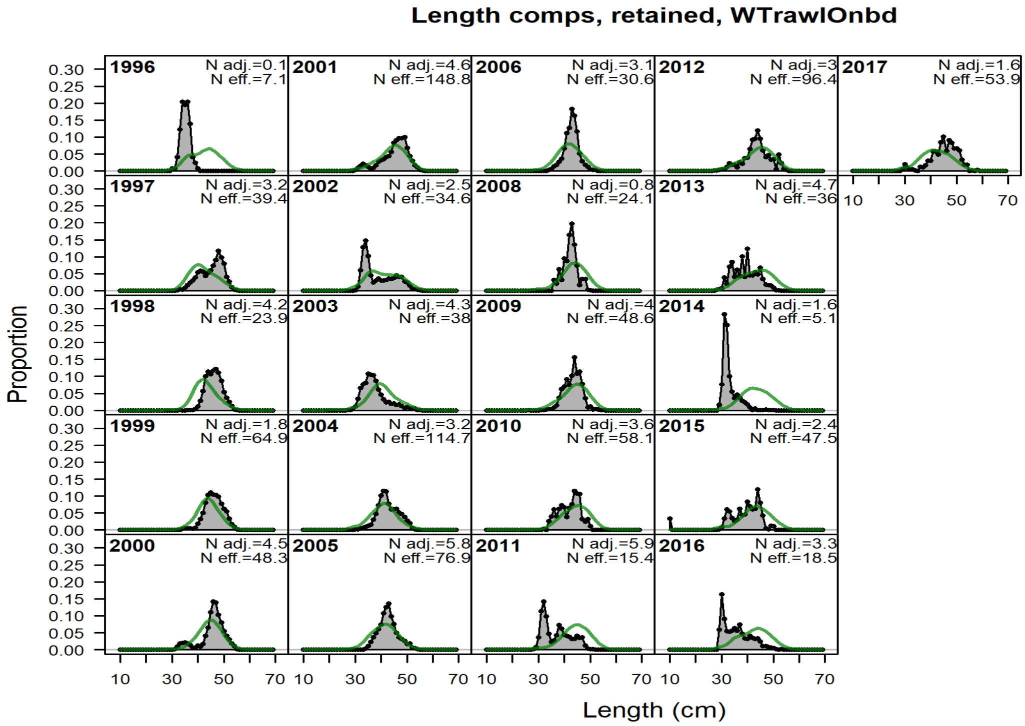


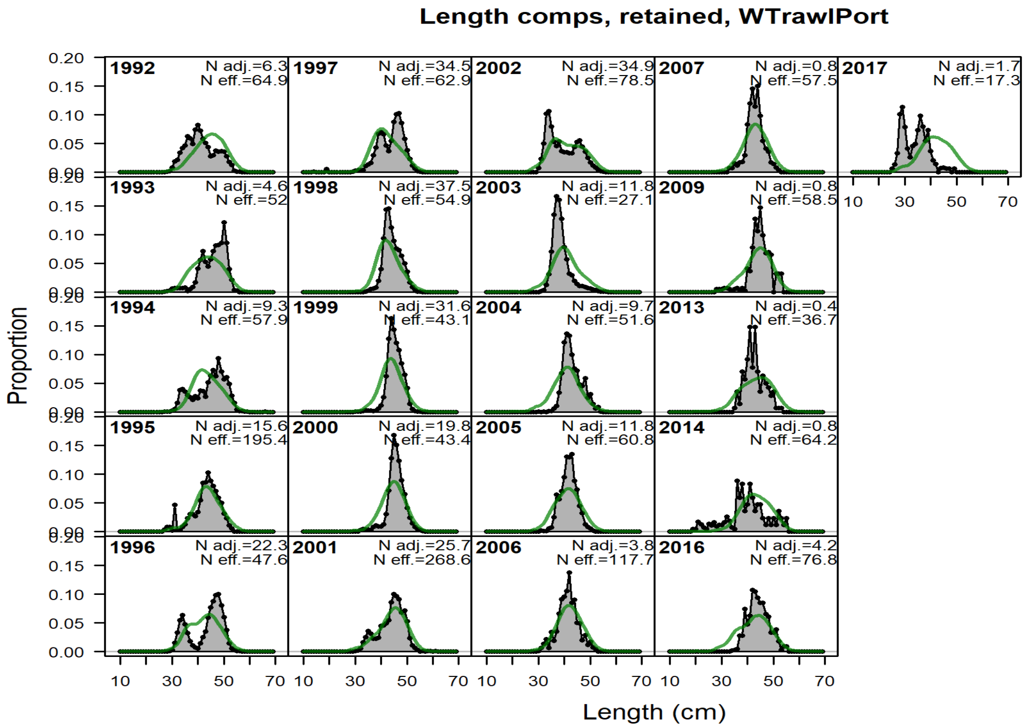
Apx Figure A.1 The observed (shaded) and model-predicted (green line) fits to the retained length composition data for silver warehou for the eastern trawl fleet onboard (top) and port (bottom).



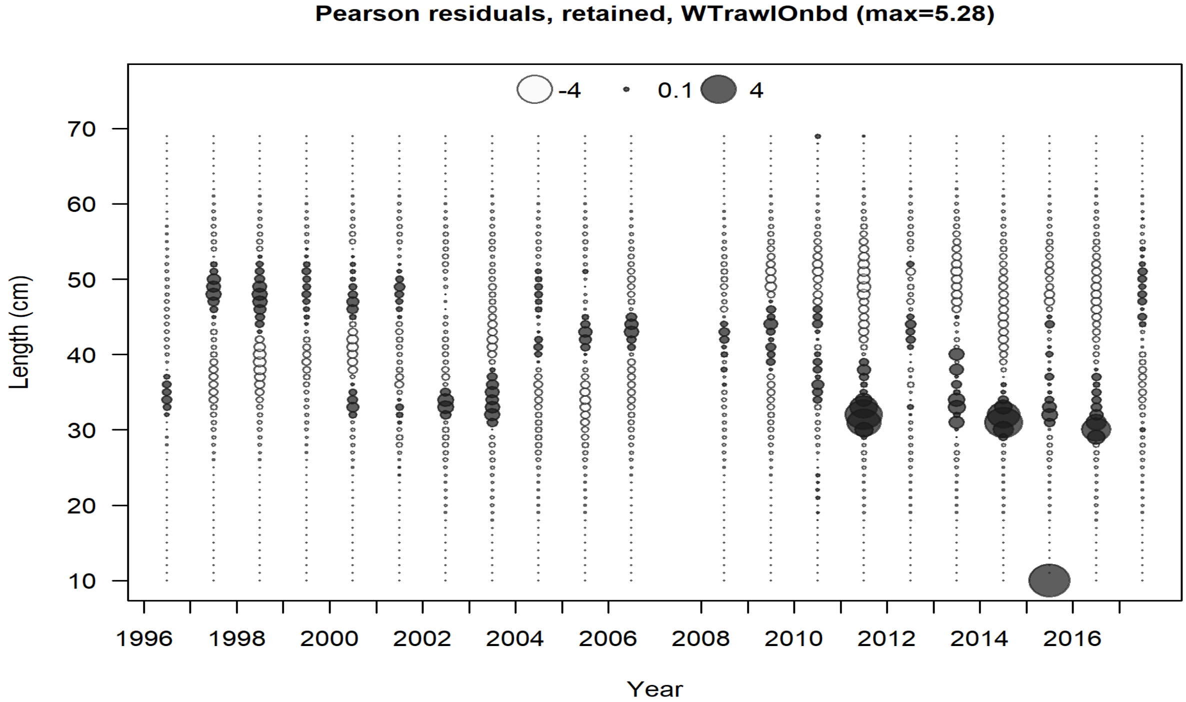


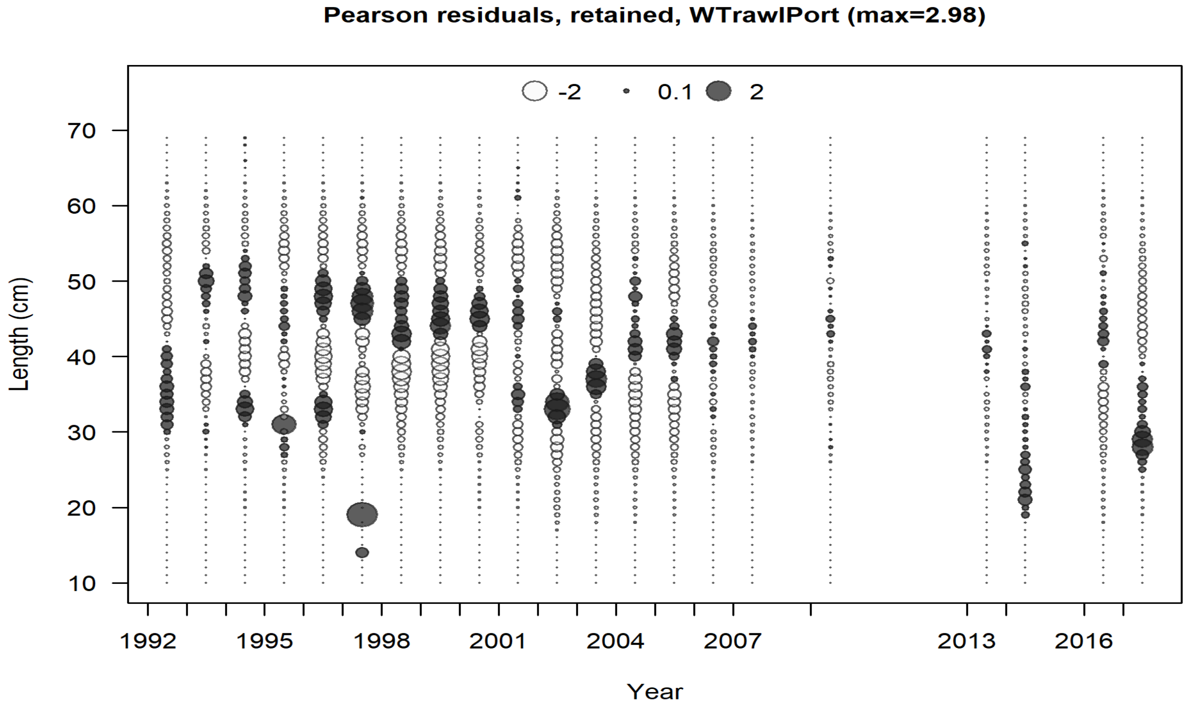
Apx Figure A.2 The residual pattern for the retained length composition data for silver warehou for the eastern trawl fleet onboard (top) and port (bottom).



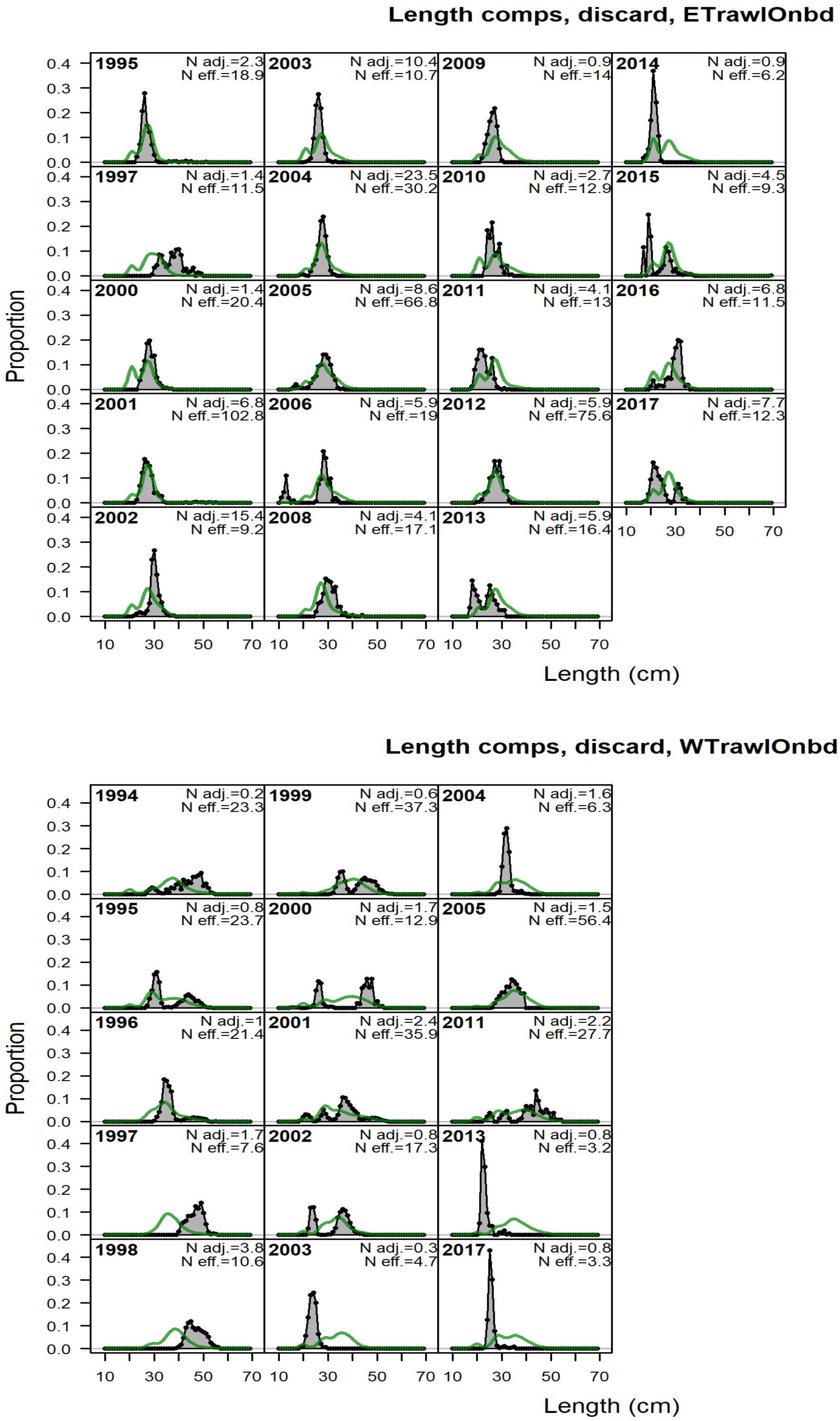


Apx Figure A.3 The observed (shaded) and model-predicted (green line) fits to the retained length composition data for silver warehou for the western trawl fleet onboard (top) and port (bottom).

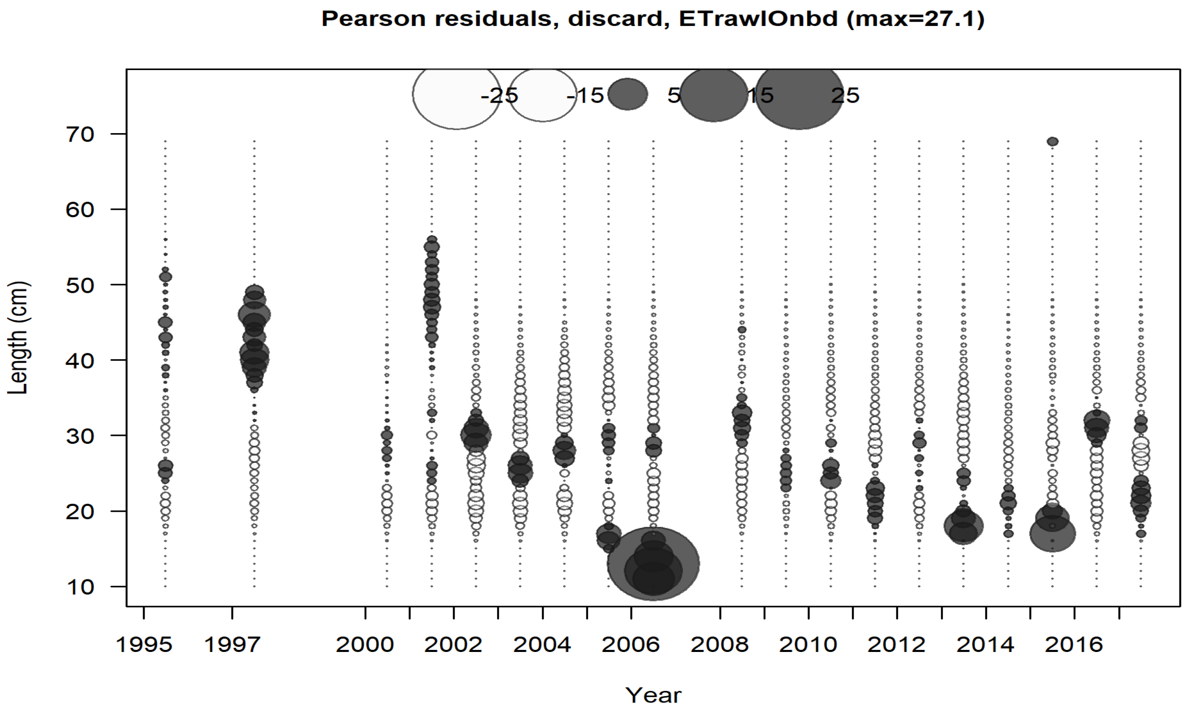


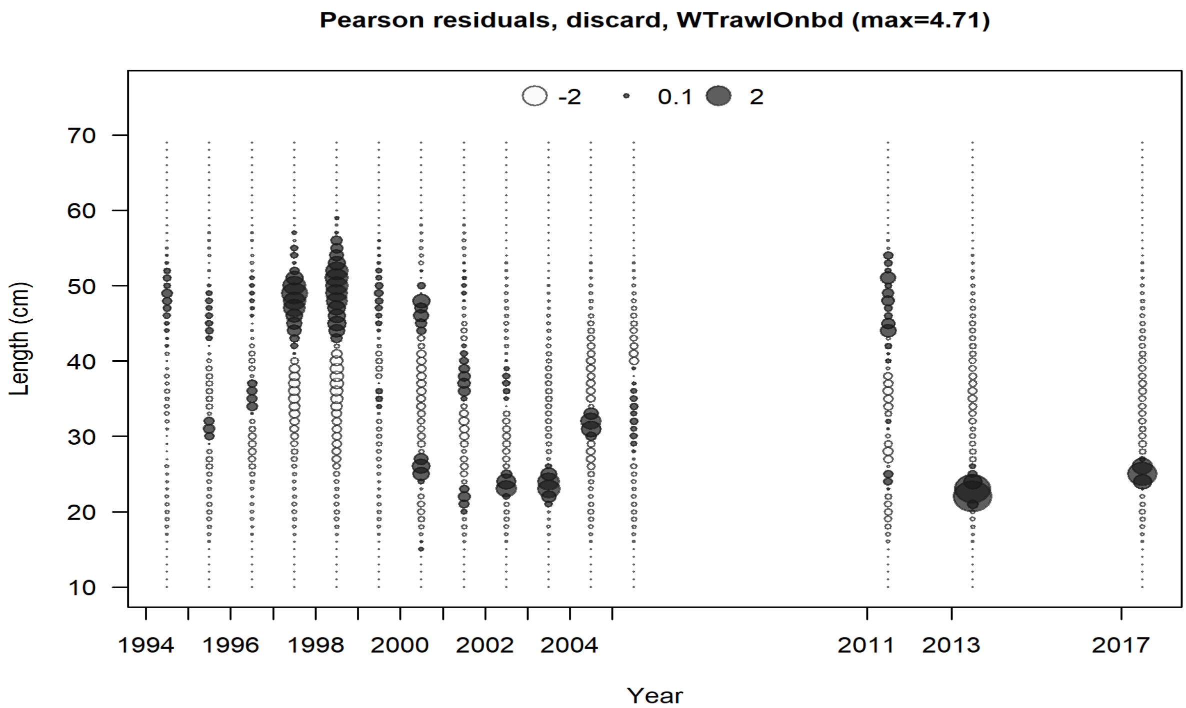


Apx Figure A.4 The residual pattern for the retained length composition data for silver warehou for the western trawl fleet onboard (top) and port (bottom).



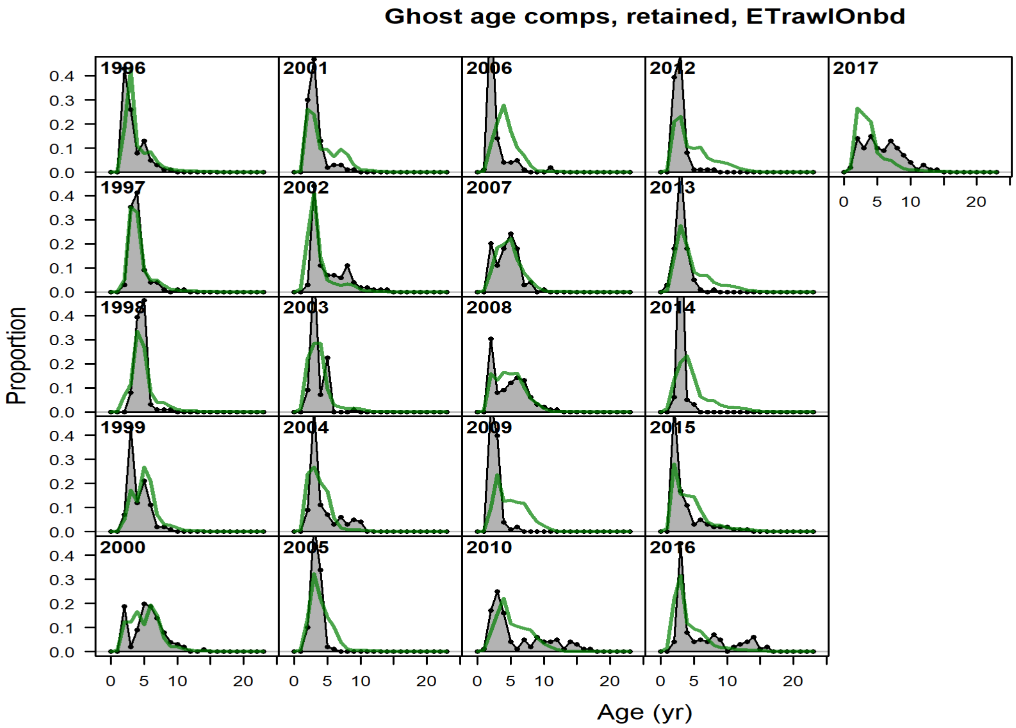
Apx Figure A.5 The observed (shaded) and model-predicted (green line) fits to the discarded length composition data for silver warehou for the eastern trawl fleet onboard (top) and western trawl fleet onboard (bottom).

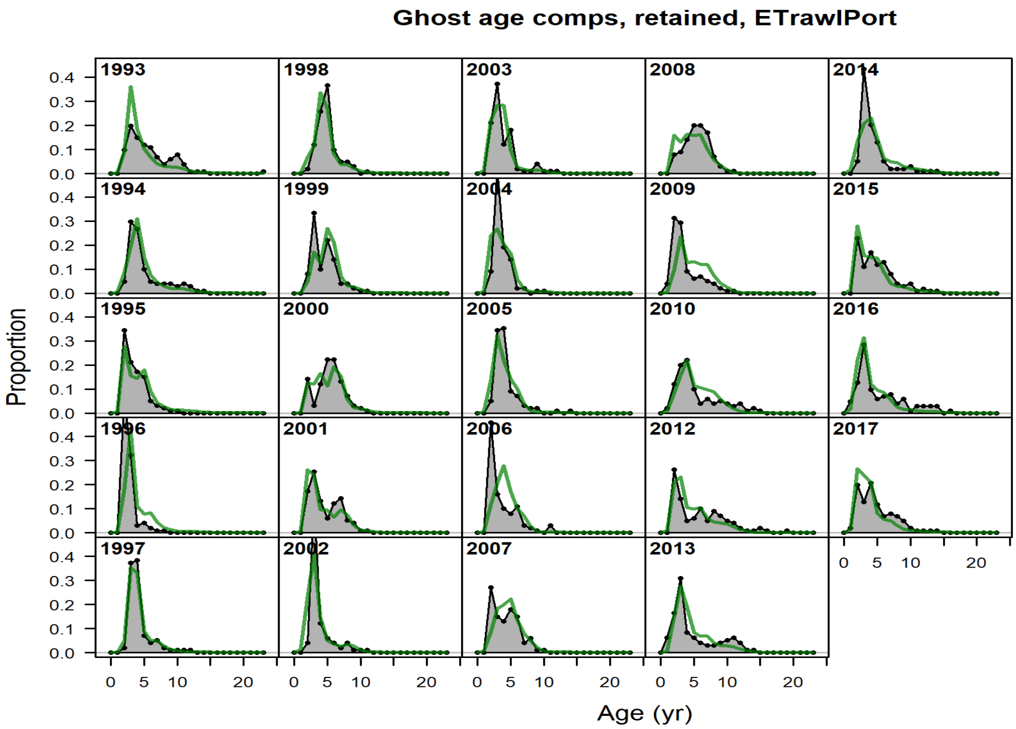




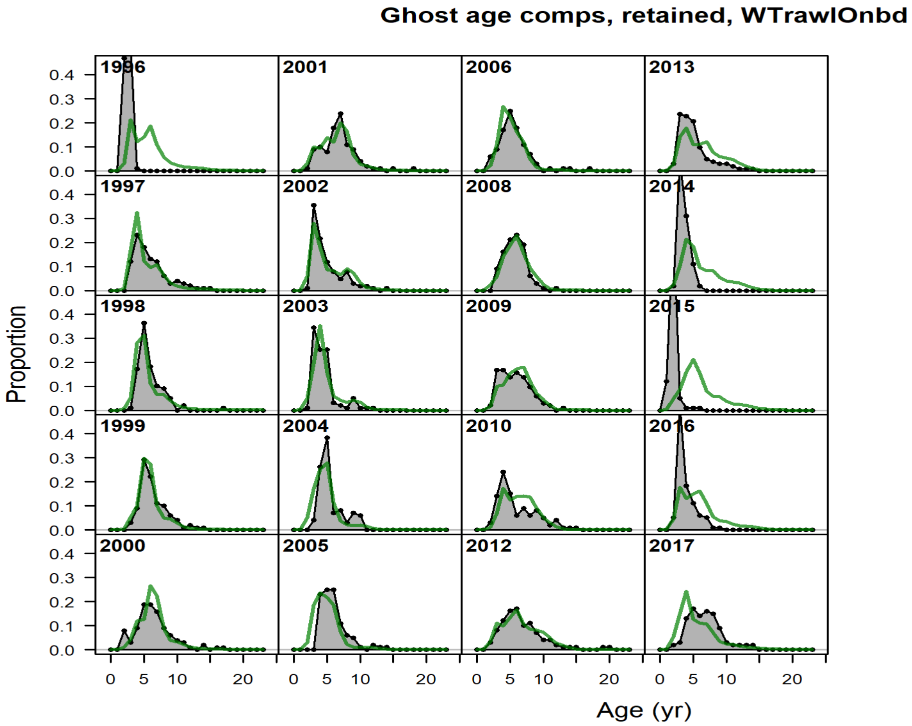
Apx Figure A.6 The residual pattern for the discarded length composition data for silver warehou for the eastern trawl fleet onboard (top) and western trawl fleet onboard (bottom).

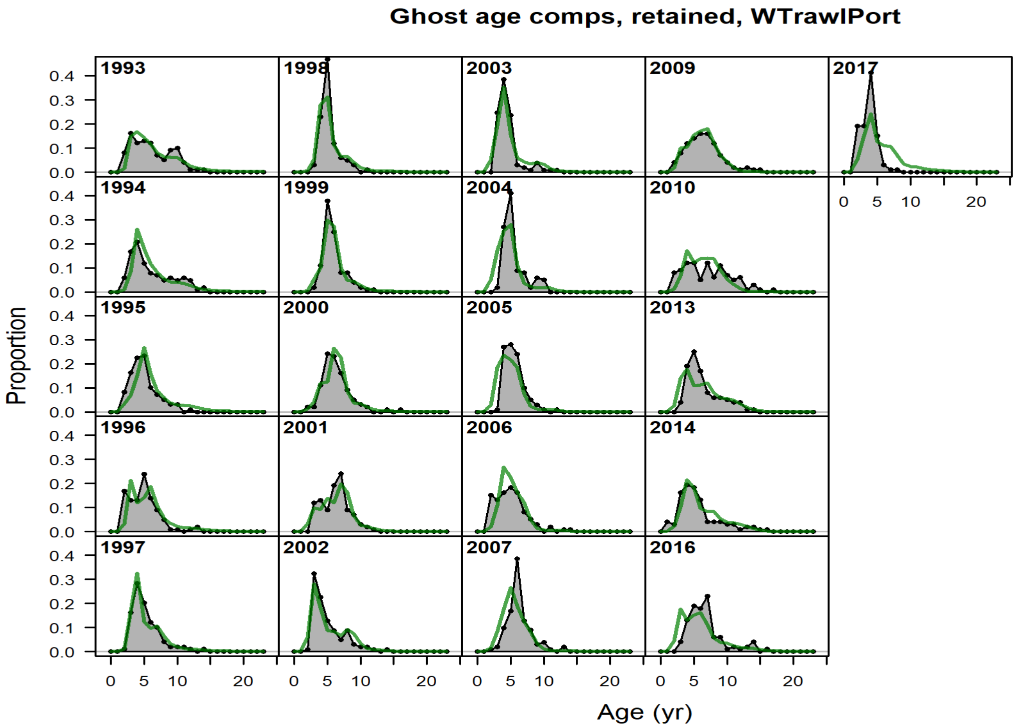
A.2 Age fits





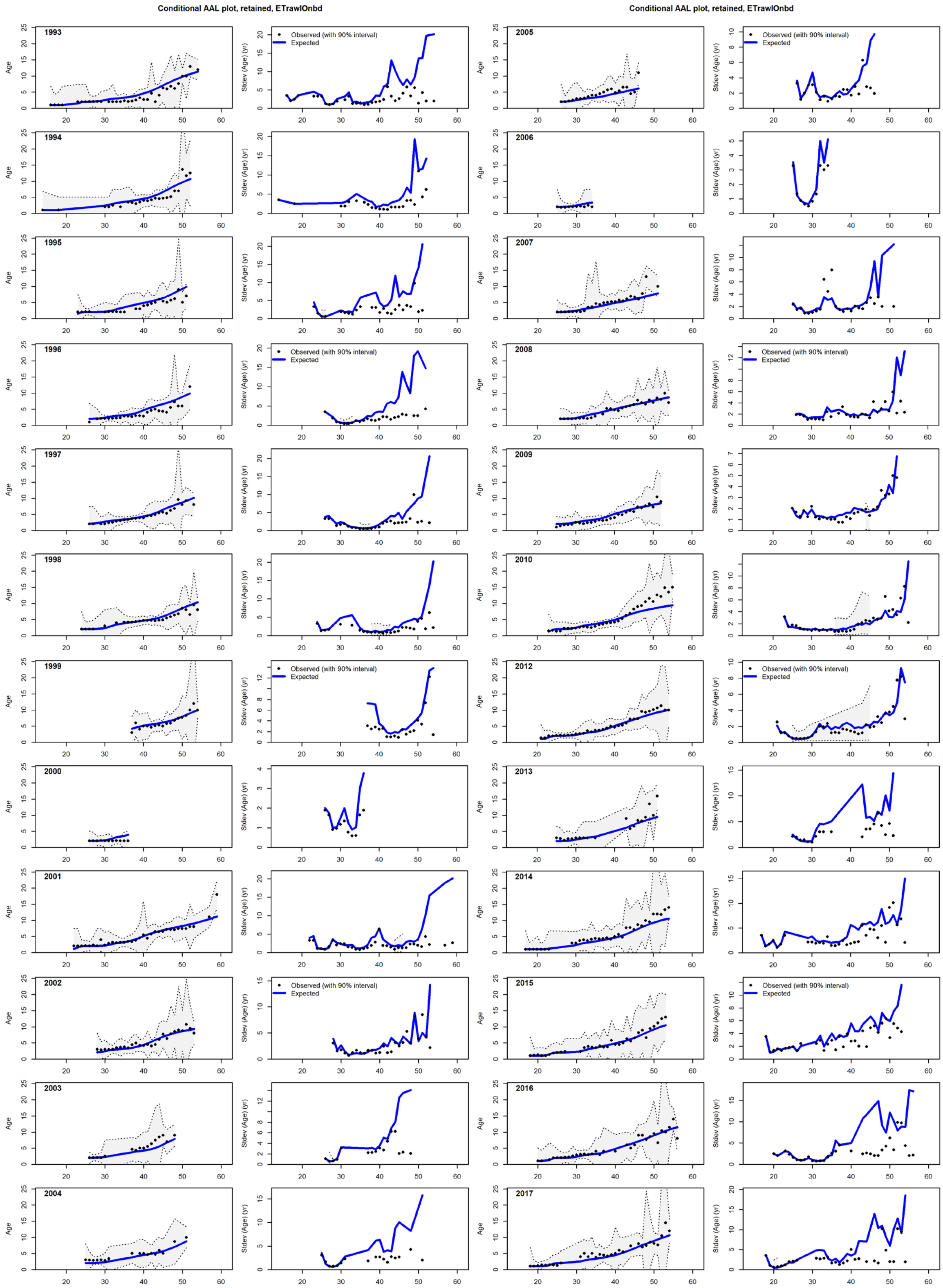
Apx Figure A.7 The observed (shaded) and model-predicted (green line) implied fits to the age composition data for silver warehou for the eastern trawl fleet onboard (top) and port (bottom).



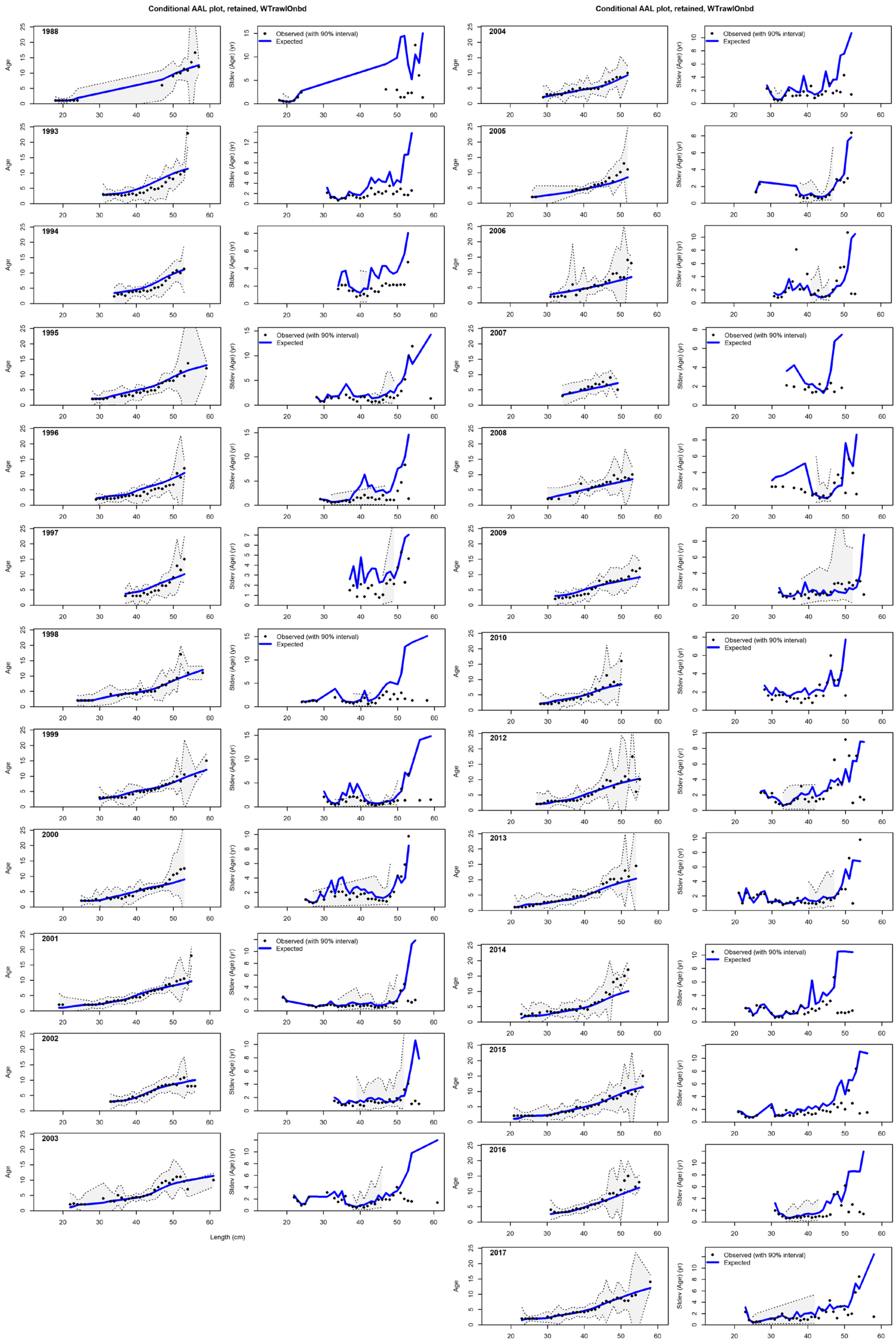


Apx Figure A.8 The observed (shaded) and model-predicted (green line) implied fits to the age composition data for silver warehou for the western trawl fleet onboard (top) and port (bottom).

A.3 Age-at-length fits

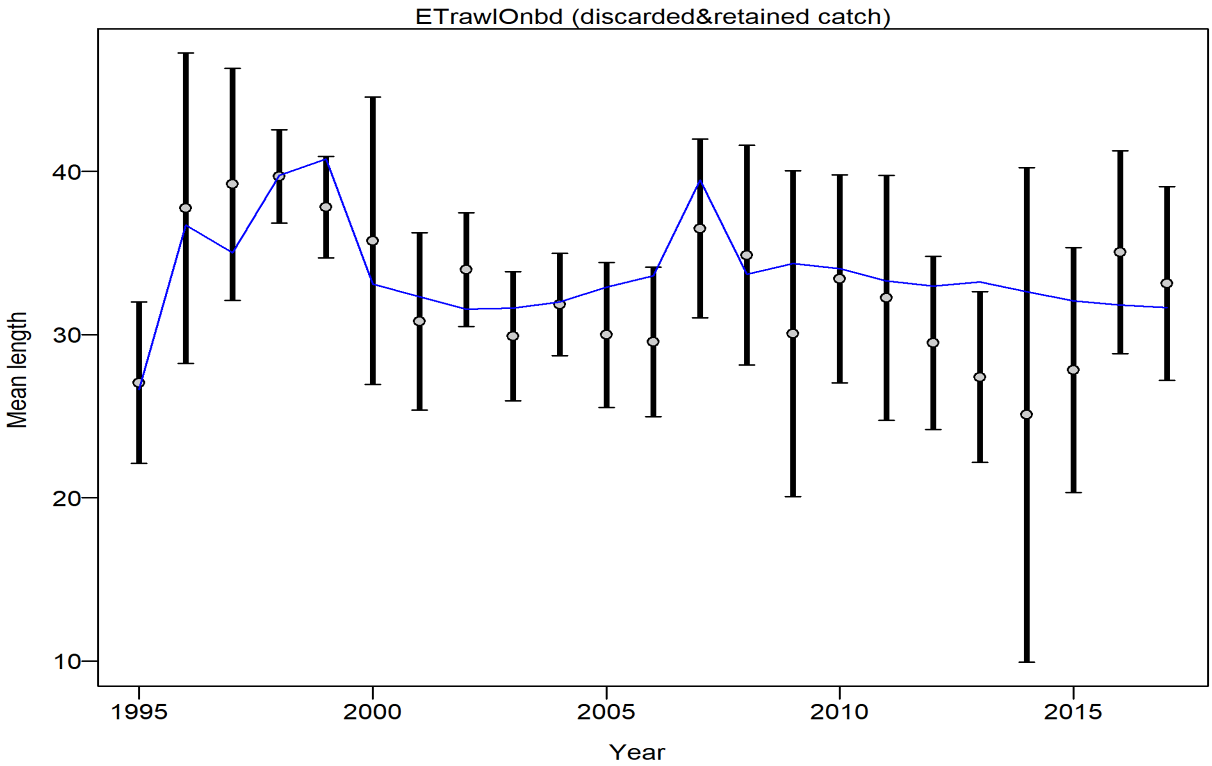


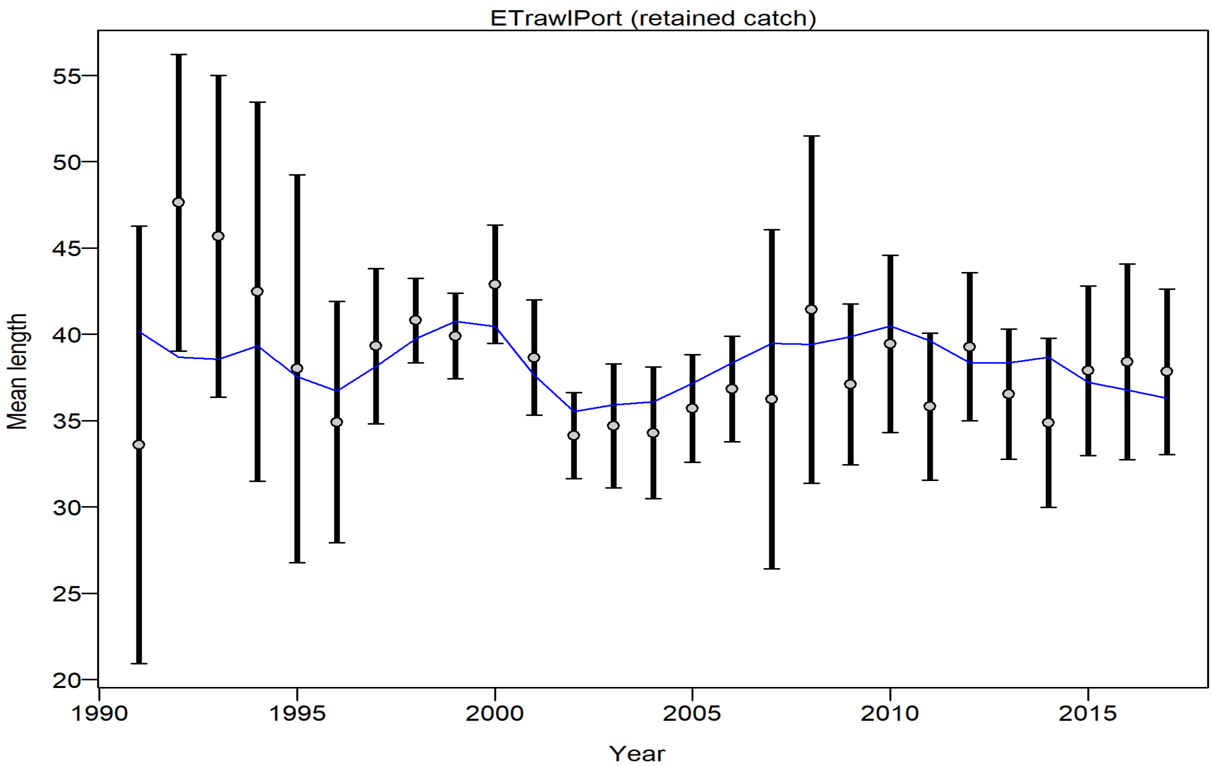
Apx Figure A.9 Fits to the conditional age-at-length for the eastern fleet using method TA1.8 of Punt (2017). Observed in black, expected in blue lines. Second and fourth columns are standard deviations.



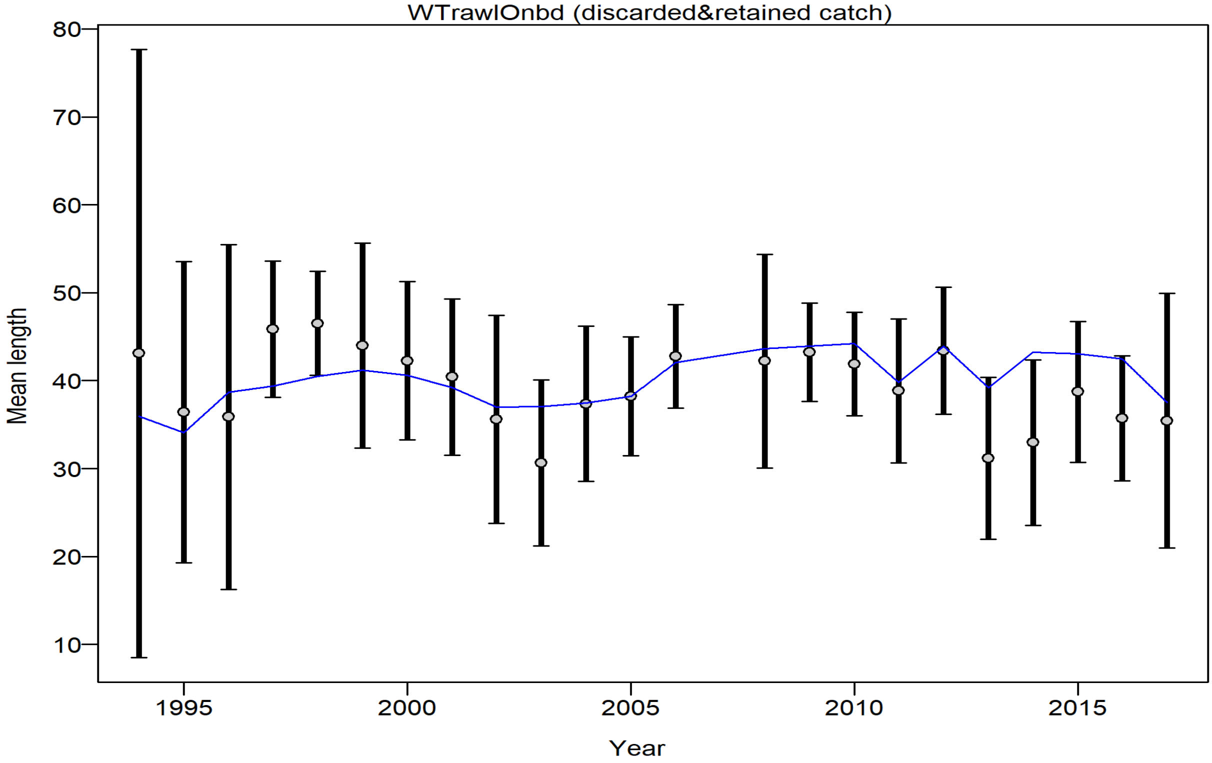
Apx Figure A.10 Fits to the conditional age-at-length for the western fleet using method TA1.8 of Punt (2017). Observed in black, expected in blue lines. Second and fourth columns are standard deviations.

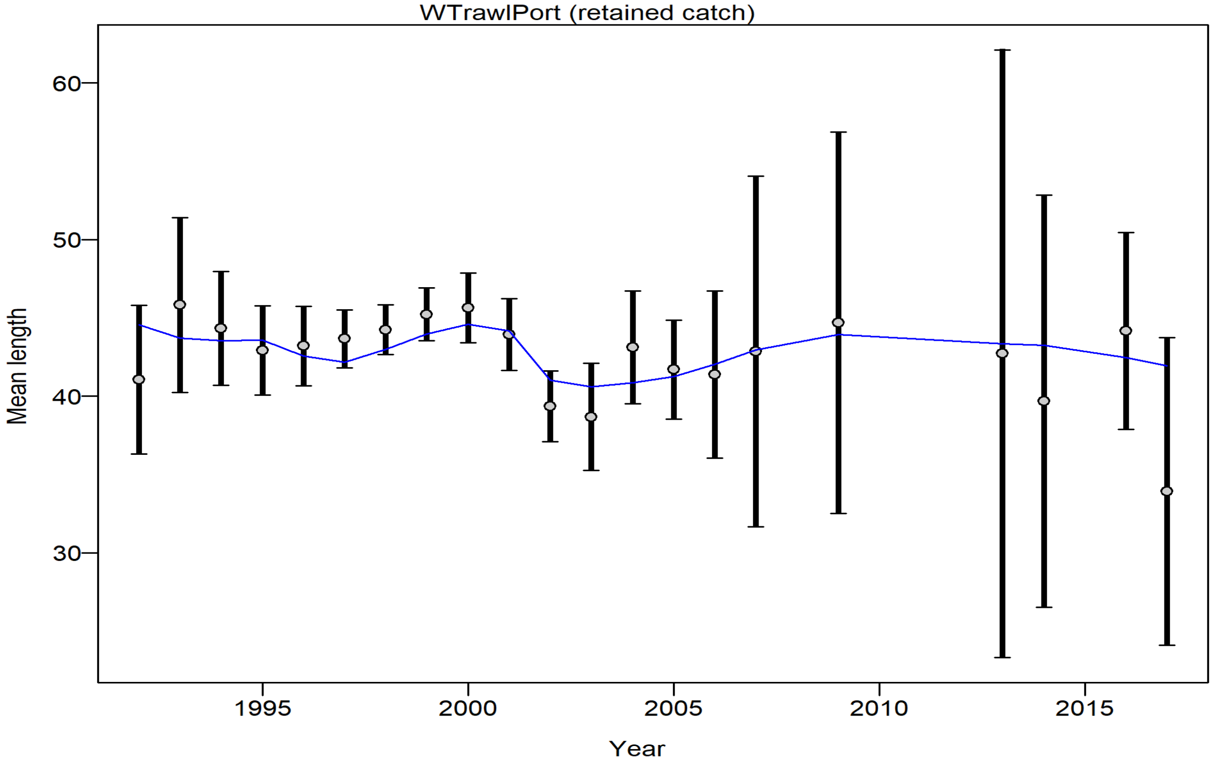
A.4 Length fit diagnostics (method TA1.8 of Punt (2017))





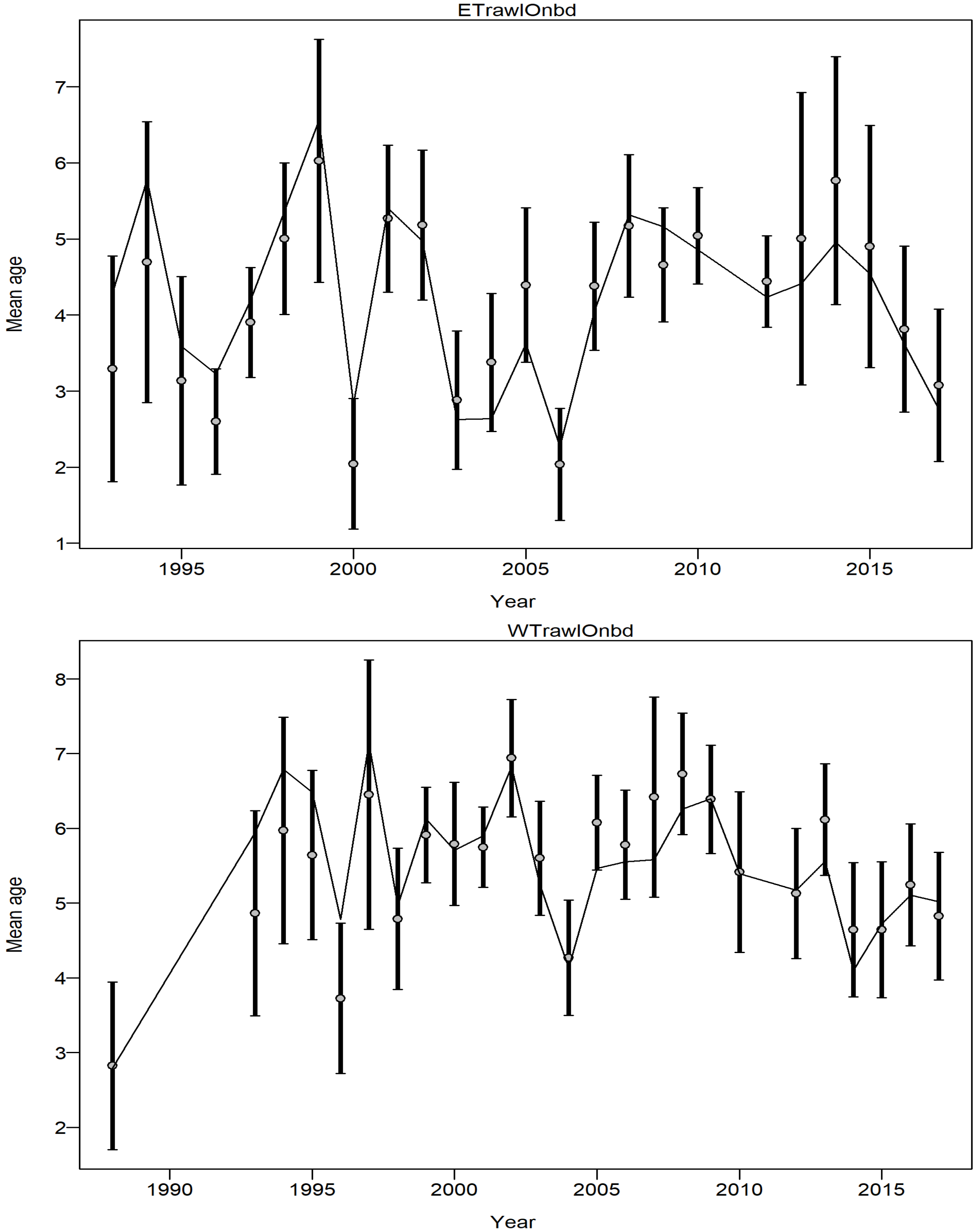
Apx Figure A.11 Length fit diagnostics obtained from conditional age-at-length weighting using method TA1.8 of Punt (2017). Eastern trawl fleet onboard (top) and port (bottom).





Apx Figure A.12 Length fit diagnostics obtained from conditional age-at-length weighting using method TA1.8 of Punt (2017). Western trawl fleet onboard (top) and port (bottom).

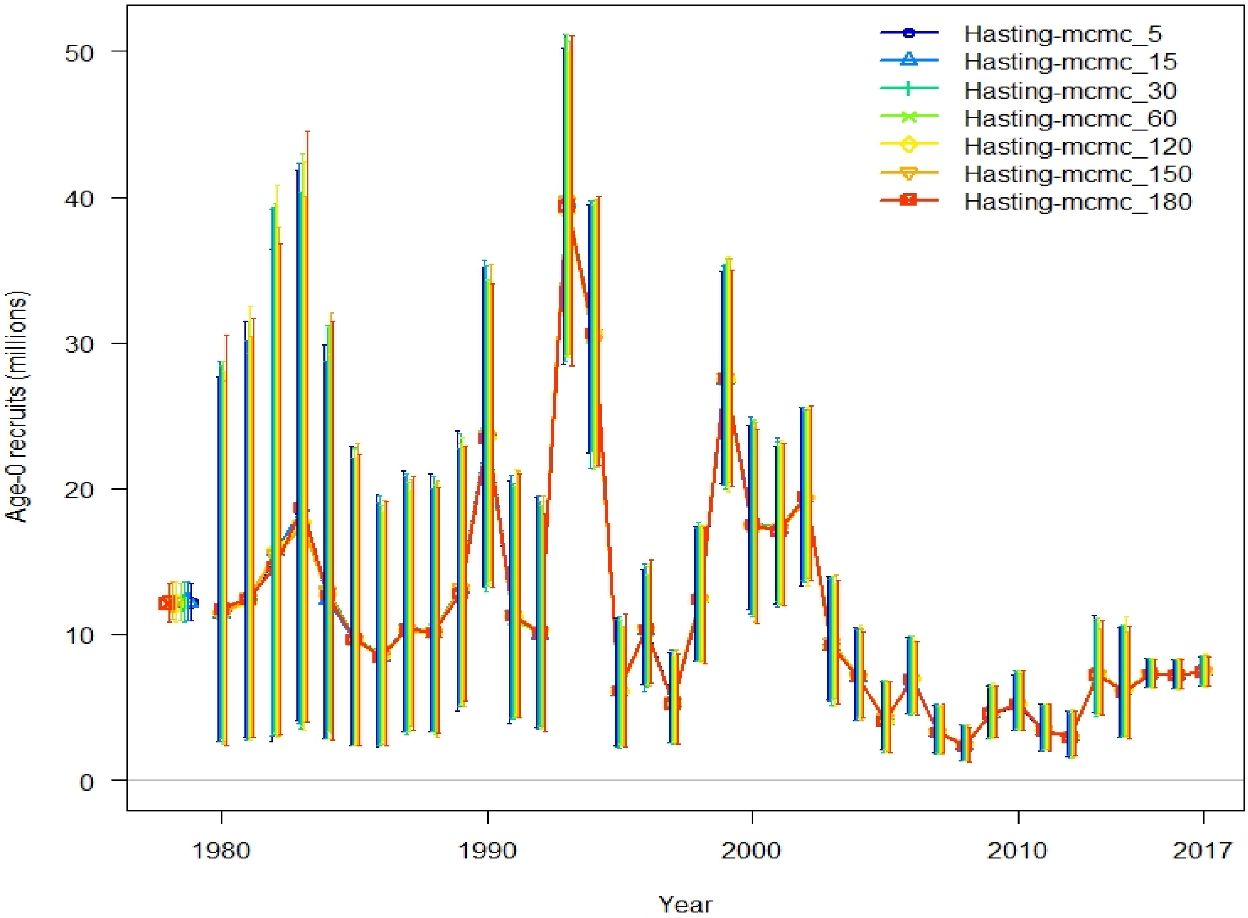
A.5 Age fit diagnostics (method TA1.8 of Punt (2017))



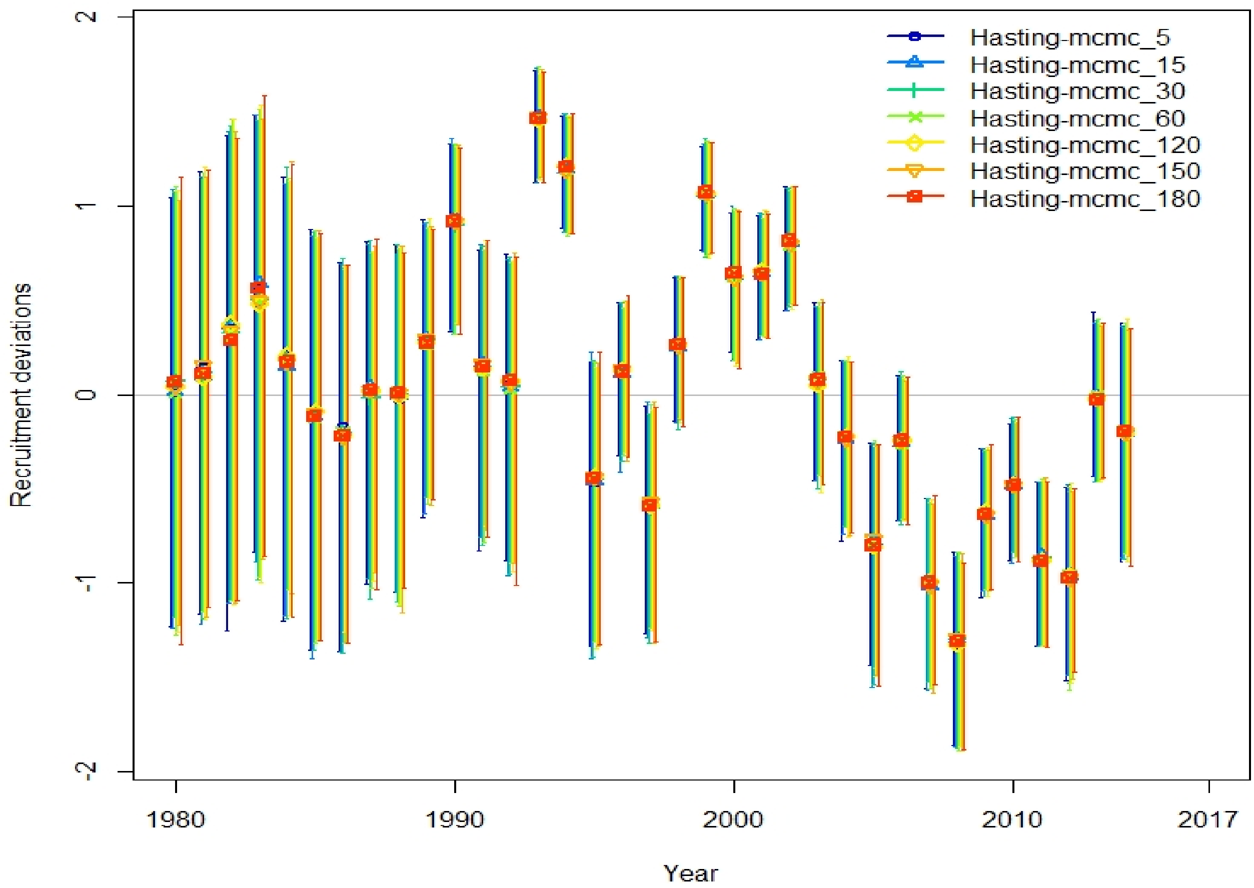
Apx Figure A.13 Age fit diagnostics obtained from conditional age-at-length weighting using method TA1.8 of Punt (2017) for eastern trawl onboard (top) and western trawl onboard (bottom).

Appendix B MCMC base case diagnostics

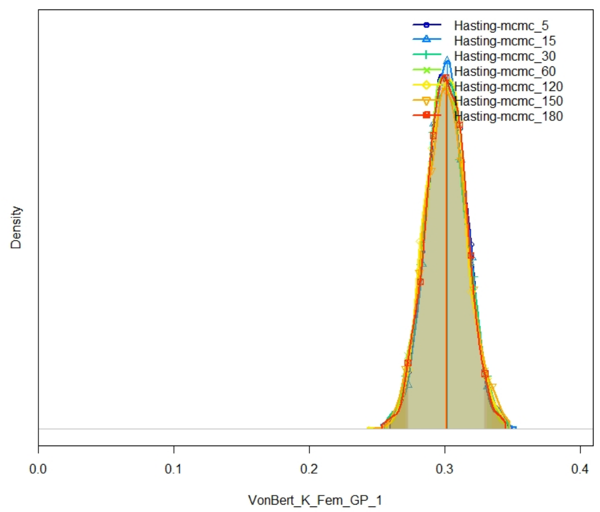
B.1 Comparison among chains

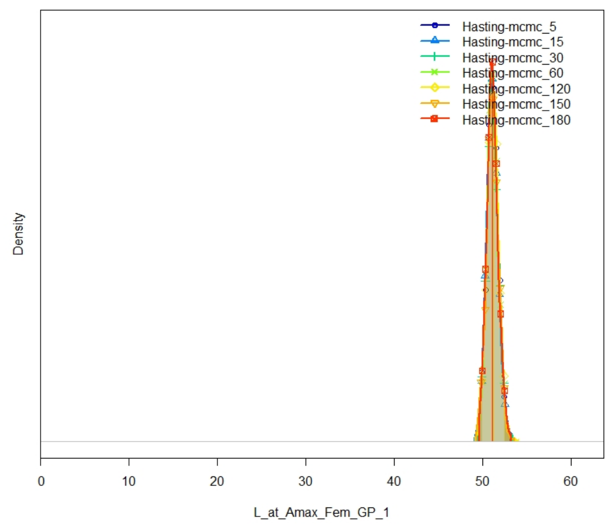


Apx Figure B.1 Estimated absolute recruitment from seven MCMC chains run for the base case assessment.



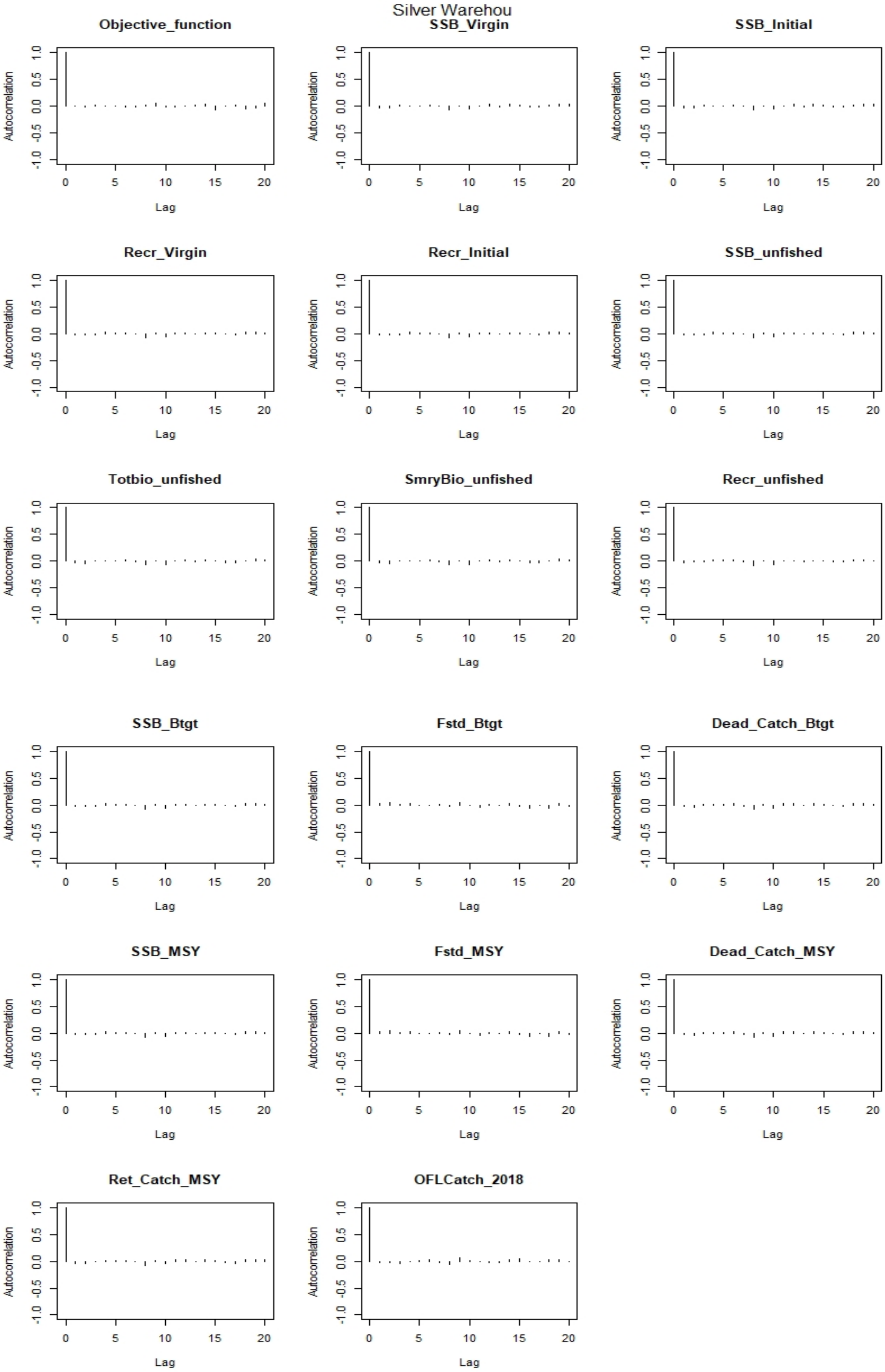
Apx Figure B.2 Estimated recruitment deviations from seven MCMC chains run for the base case assessment.



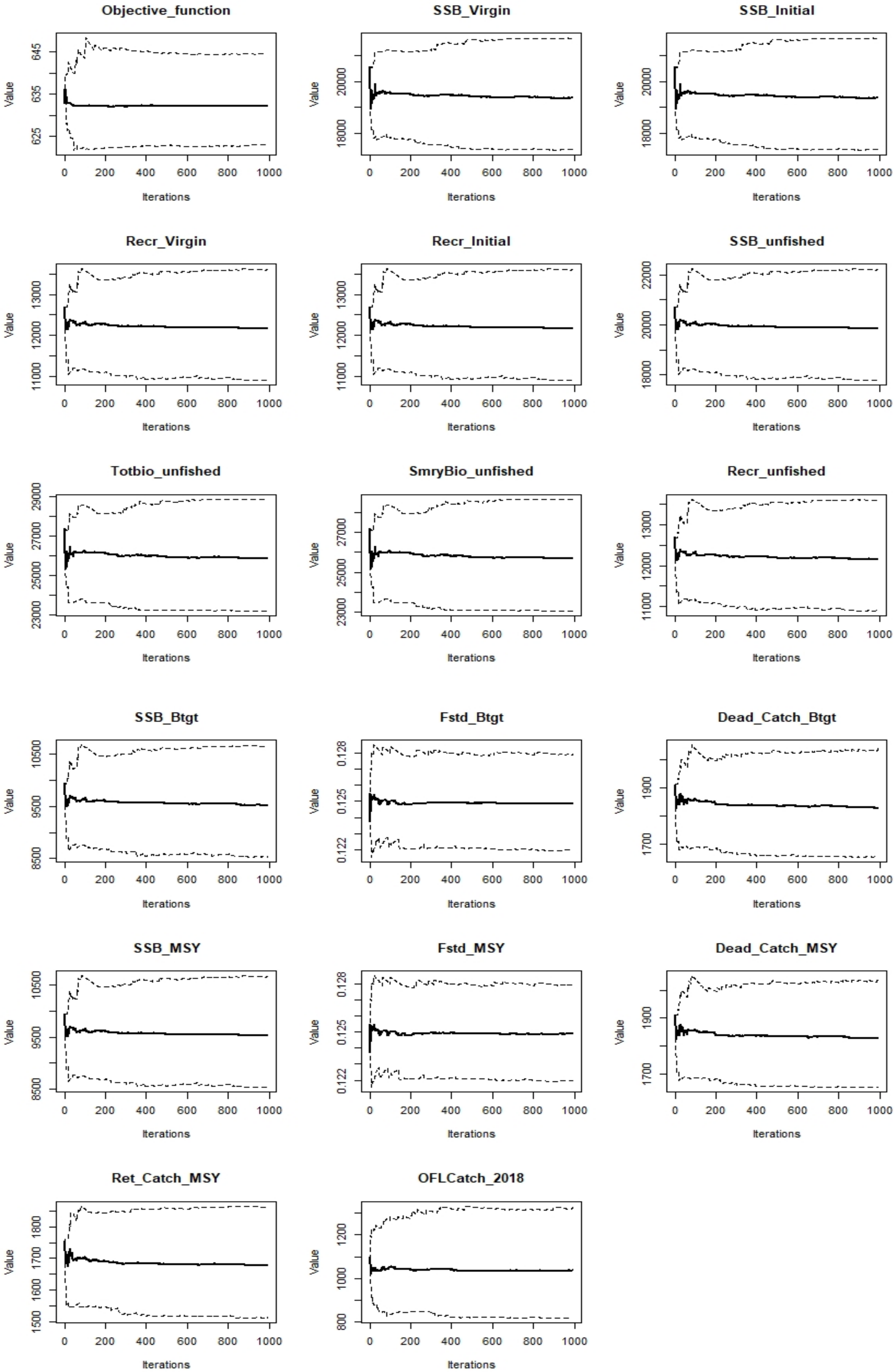


Apx Figure B.3 Estimated von Bertalanffy growth parameters K (left) and mean length at maximum age (right) from seven MCMC chains run for the base case assessment.

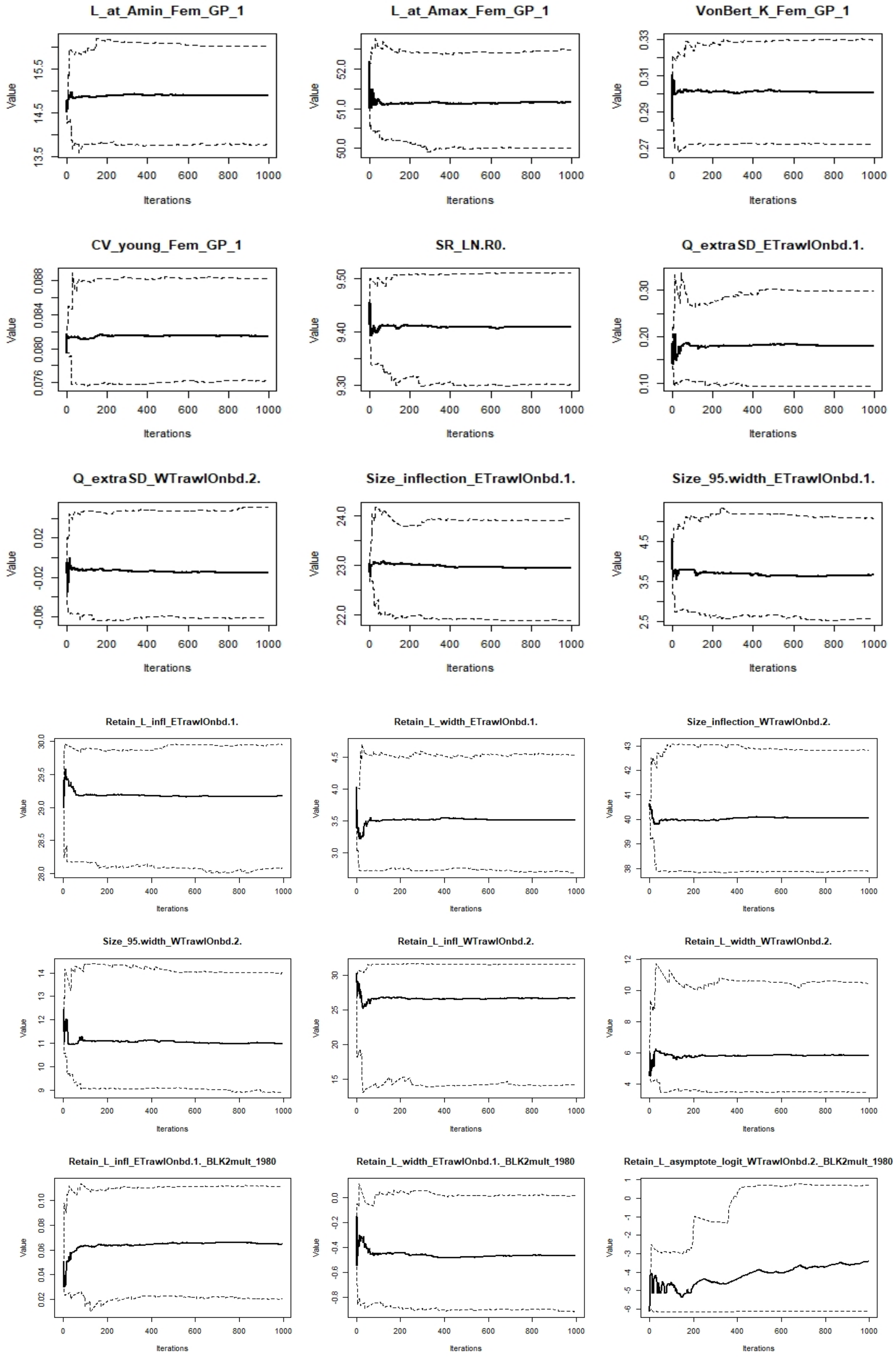
B.2 MCMC Diagnostics



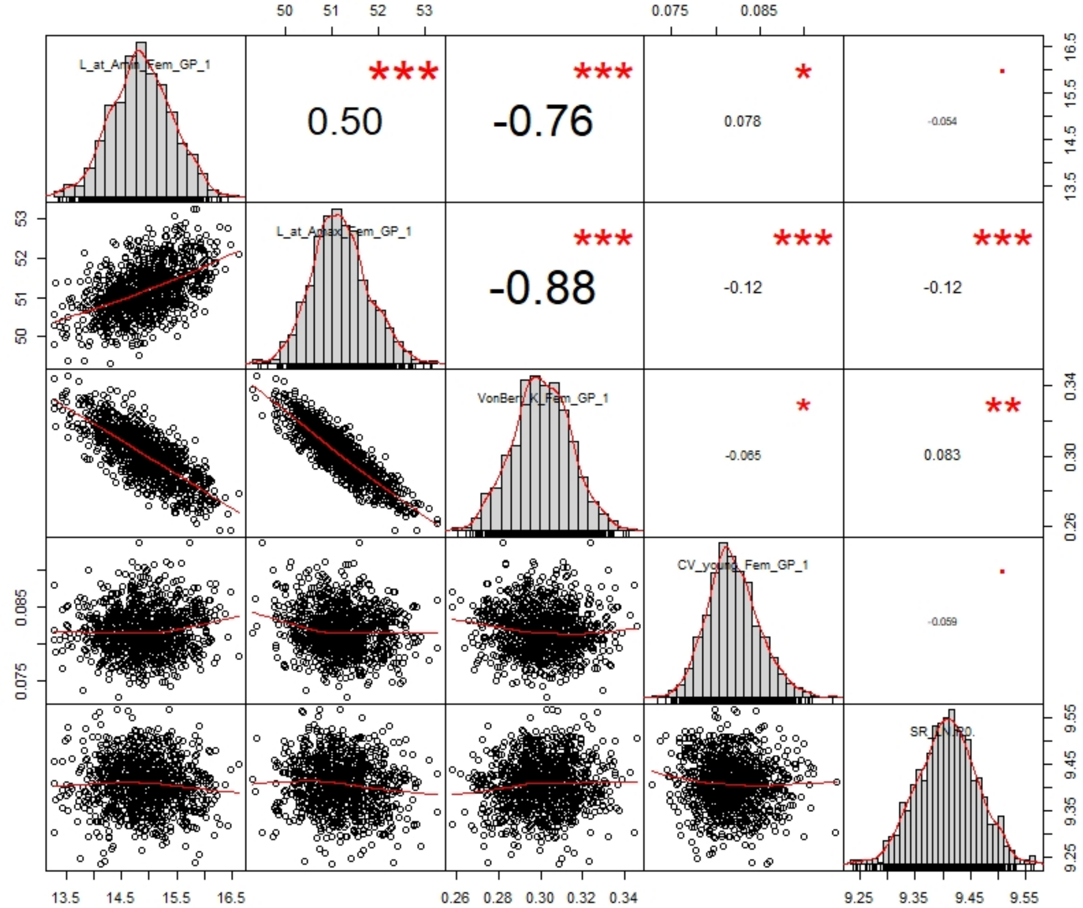
Apx Figure B.4 Autocorrelation plots for time series from MCMC analysis



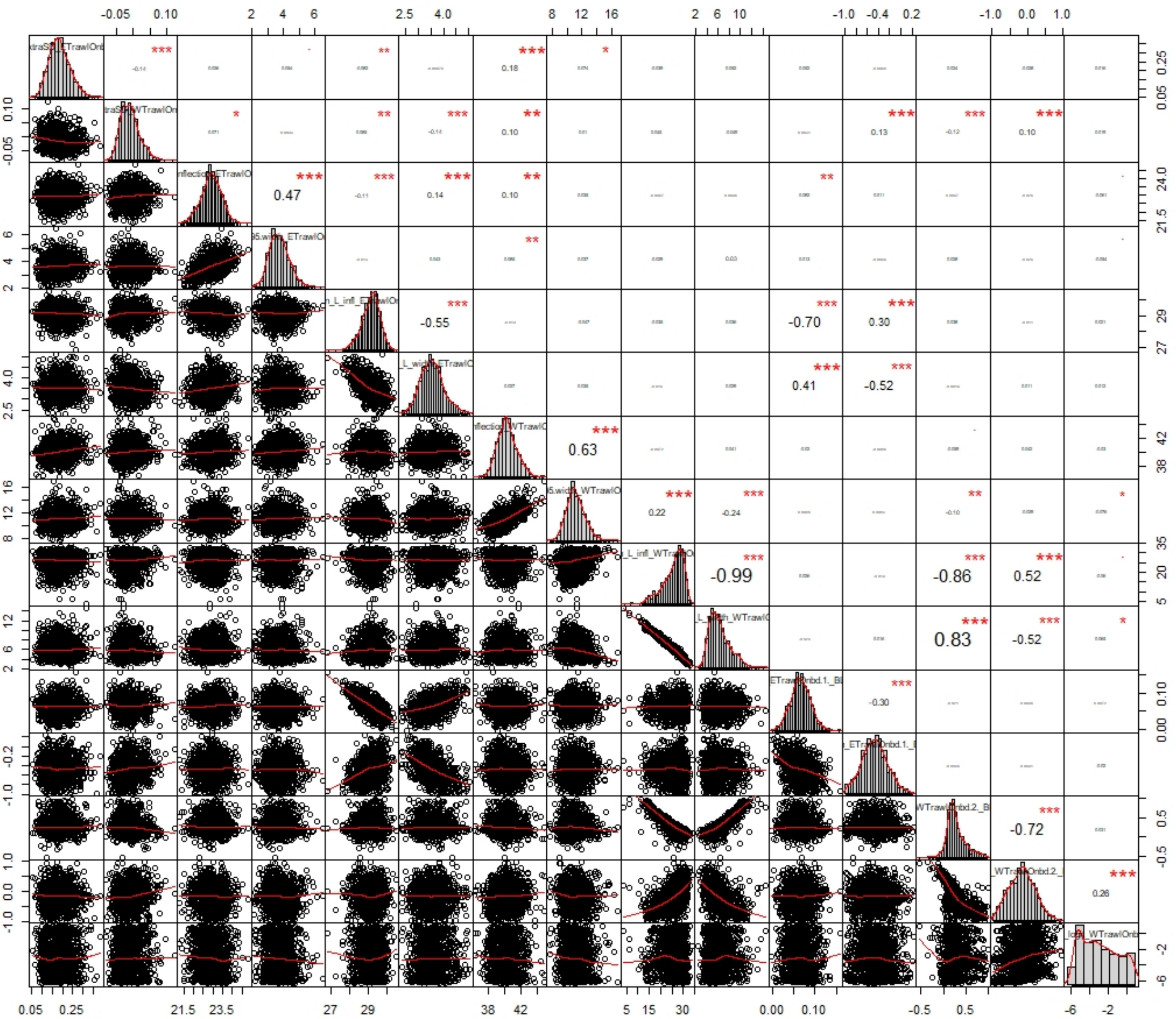
Apx Figure B.5 Trace plot of time series for the base case from MCMC analysis.



Apx Figure B.6 Trace plots of growth, selectivity and retention parameters for the base case from MCMC analysis.



Apx Figure B.7 Autocorrelation matrix and kernel density overlays of growth parameters estimated from the posterior distribution for base case assessment. Asterisks indicate statistical significance (0.05, 0.01 and 0.001).

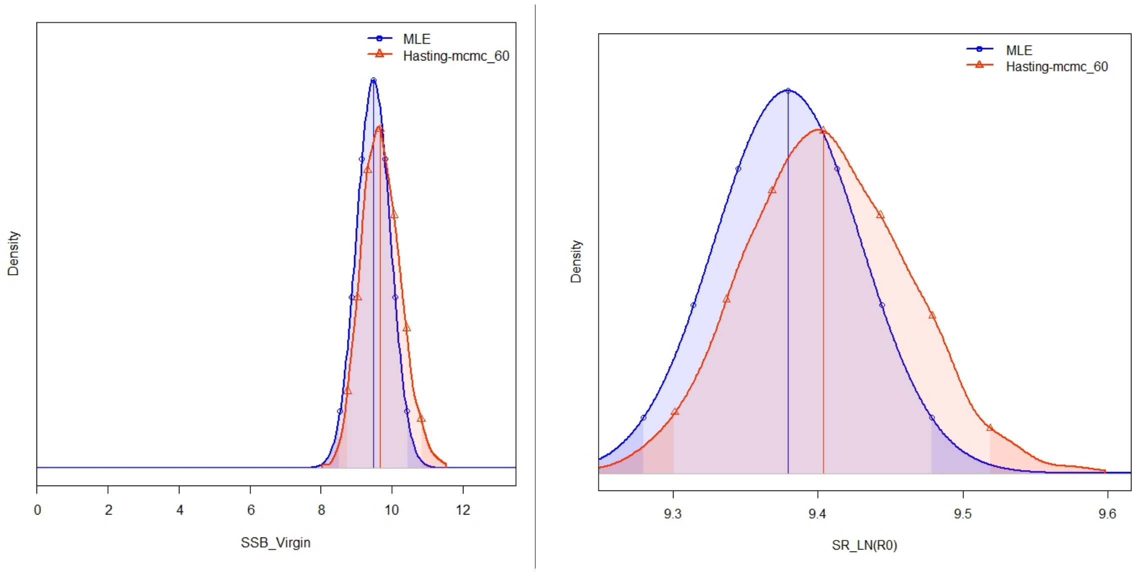


Apx Figure B.8 Autocorrelation matrix and kernel density overlays of selectivity parameters estimated from the posterior distribution for base case assessment. Asterisks indicate statistical significance (0.05, 0.01 and 0.001).

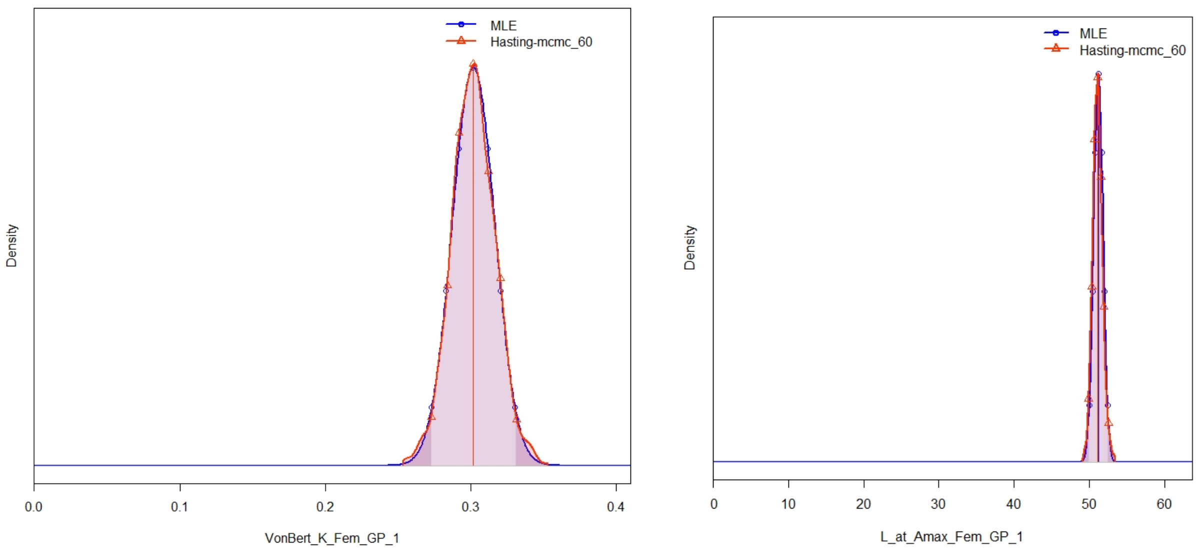
Apx Table B1. Median estimates of key parameters with 95% credible intervals along with Geweke and Heidelberger and Welch tests derived from seven MCMC chains. Chain 4 (shaded grey) was used for results shown in this report.

Chain	Parameter	Median (0.025, 0.975)	AC Lag1	Eff.N	Geweke-Z	Heidel-W
Chain 1	VonBert_K_Fem_GP_1	0.300 (0.27,0.32)	0.036	795	-0.207	Passed
Chain 1	SR_LN(R0)	9.404 (9.31, 9.50)	0.003	795	0.027	Passed
Chain 1	Main_RecrDev_2008	-1.32 (-1.79, -0.908)	0.017	795	0.484	Passed
Chain 1	Q_extraSD_ETrawlOnbd.1.	0.173 (0.106, 0.274)	-0.03	795	0.369	Passed
Chain 1	Q_extraSD_ETrawlOnbd.2.	-0.015 (-0.05, -0.03)	0.004	795	-2.49	Passed
Chain 2	VonBert_K_Fem_GP_1	0.301 (0.278, 0.326)	-0.002	795	-0.089	Passed
Chain 2	SR_LN(R0)	9.40 (9.31, 9.49)	-0.007	664	2.175	Passed
Chain 2	Main_RecrDev_2008	-1.30 (-1.80, - 0.936)	0.06	510	-0.791	Failed
Chain 2	Q_extraSD_ETrawlOnbd.1.	0.17 (0.103, 0.275)	-0.029	795	1.227	Passed
Chain 2	Q_extraSD_ETrawlOnbd.2.	-0.016 (-0.05, 0.04)	0.014	795	0.491	Passed
Chain 3	VonBert_K_Fem_GP_1	0.300 (0.276, 0.326)	-0.094	795	1.544	Passed
Chain 3	SR_LN(R0)	9.403 (9.31, 9.50)	-0.044	795	-0.54	Passed
Chain 3	Main_RecrDev_2008	-1.29 (-1.78, -0.919)	-0.038	795	0.4	Passed
Chain 3	Q_extraSD_ETrawlOnbd.1.	0.178 (0.10, 0.27)	-0.029	795	-1	Passed
Chain 3	Q_extraSD_ETrawlOnbd.2.	-0.017 (-0.05, 0.04)	-0.026	795	0.771	Passed
Chain 4	VonBert_K_Fem_GP_1	0.300 (0.276, 0.326)	0.041	795	0.793	Passed
Chain 4	SR_LN(R0)	9.403 (9.31, 9.50)	0.053	795	0.632	Passed
Chain 4	Main_RecrDev_2008	-1.32 (-1.771, -0.921)	-0.006	795	-0.553	Passed
Chain 4	Q_extraSD_ETrawlOnbd.1.	0.181 (0.102, 0.44)	0.018	795	1.829	Passed
Chain 4	Q_extraSD_ETrawlOnbd.2.	0.016 (-0.05, 0.04)	-0.012	795	0.463	Passed
Chain 5	VonBert_K_Fem_GP_1	0.300 (0.277, 0.326)	-0.083	795	-0.02	Passed
Chain 5	SR_LN(R0)	9.40 (9.30 -9.499)	-0.073	795	-1.099	Passed
Chain 5	Main_RecrDev_2008	-1.327 (-1.767, - 0.941)	0.025	795	0.179	Passed
Chain 5	Q_extraSD_ETrawlOnbd.1.	0.177 (0.10, 0.275)	-0.043	795	1.253	Passed
Chain 5	Q_extraSD_ETrawlOnbd.2.	-0.01 (-0.05, 0.04)	0.064	795	0.391	Passed
Chain 6	VonBert_K_Fem_GP_1	0.300 (0.277, 0.326)	-0.131	795	1.284	Passed
Chain 6	SR_LN(R0)	9.40 (9.30, 9.499)	-0.005	795	0.698	Passed
Chain 6	Main_RecrDev_2008	-1.299 (-1.794,- 0.91)	0.042	795	-0.018	Passed
Chain 6	Q_extraSD_ETrawlOnbd.1.	0.177 (0.10, 0.275)	0.004	795	0.778	Passed
Chain 6	Q_extraSD_ETrawlOnbd.2.	-0.01 (-0.05, 0.04)	-0.063	795	-0.694	Passed
Chain 7	VonBert_K_Fem_GP_1	0.300 (0.277, 0.326)	-0.024	795	0.191	Passed
Chain 7	SR_LN(R0)	9.40 (9.30, 9.499)	0.0005	795	-1.228	Passed
Chain 7	Main_RecrDev_2008	-1.306 (-1.80, - 0.95)	0.038	795	-0.066	Passed
Chain 7	Q_extraSD_ETrawlOnbd.1.	0.173 (0.10, 0.26)	0.018	758	0.599	Passed
Chain 7	Q_extraSD_ETrawlOnbd.2.	-0.01 (-0.05, -0.04)	-0.002	795	-1.07	Passed

B.3 Comparison with maximum likelihood estimate



Apx Figure B.9 Comparison of a single MCMC chain with the maximum likelihood estimate (MLE) estimate of virgin spawning biomass (left) and log of virgin recruitment (right).



Apx Figure B.10 Comparison of a single MCMC chain with the maximum likelihood estimate (MLE) estimate of von Bertalanffy growth parameters K (left) and mean length at maximum age (right).

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