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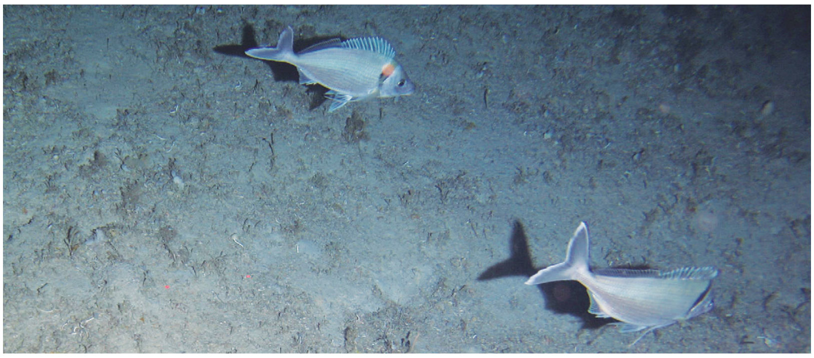
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2016 and 2017



PART 2

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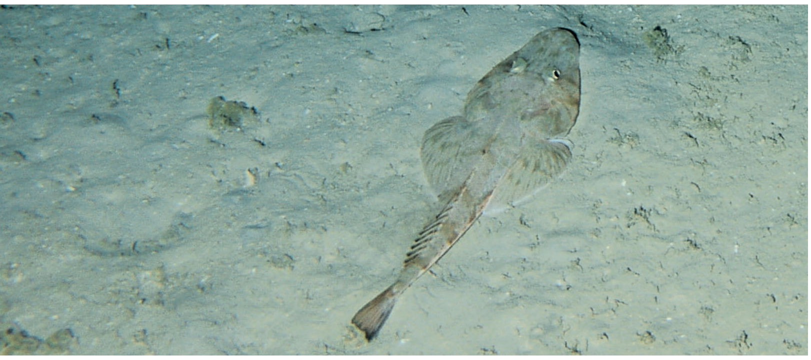

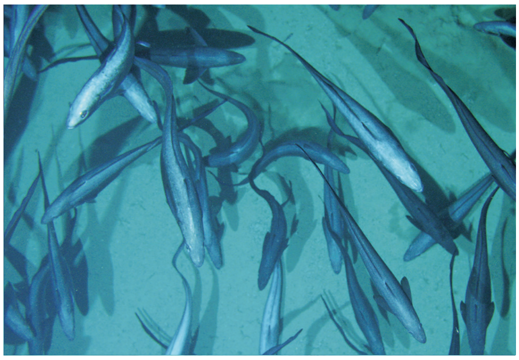

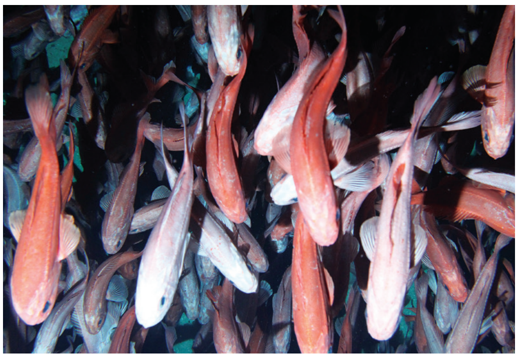

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Cover photographs

Front cover, jackass morwong, orange roughy, blue grenadier, and flathead.

Report structure

Parts 1 and 2 of this report describe the assessments of 2016 and 2017 respectively

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2016 and 2017

Part 2: 2017

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Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2017

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15. School whiting (*Sillago flindersi*) stock assessment based on data up to 2016

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15.1 Executive Summary

This document updates the 2009 assessment of school whiting (*Sillago flindersi*) to provide estimates of stock status in the SESSF at the start of 2018 and describes the base case assessment and some of the issues encountered during development. This assessment was performed using the stock assessment package Stock Synthesis (version V3.30.08.03). The 2009 stock assessment has been updated with the inclusion of data up to the end of 2016, comprising an additional eight years of catch, discard, CPUE, length and age data and ageing error updates. A range of sensitivities were explored.

A preliminary base case was presented at the September SERAG meeting and a provisional base case at the November SERAG meeting, with improvements to the balancing of the conditional age-at-length in the provisional base case and incorporating fixes to a bug discovered in Stock Synthesis in the interim. Following the November SERAG meeting, the November provisional base case was updated by changing the spawning month from July to January, at the request of SERAG, and a further variation was produced with improvements to the estimated growth curve, again with January spawning. This gave a choice of 3 fully balanced alternative base cases to be considered by SERAG in December 2017. SERAG chose the base case with January spawning and improved growth fits (listed as Sensitivity 17 in this report).

The base-case assessment estimates that current spawning stock biomass is 47% of unexploited stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2018 recommended biological catch (RBC) is 1,606 t, with the long term yield (assuming average recruitment in the future) of 1,641 t. The average RBC over the three year period 2018-2020 is 1,615 t and over the five year period 2018-2022, the average RBC is 1,621 t.

Exploration of model sensitivity showed variation in spawning biomass across all sensitivities ranging from 39% to 57% of SSB_0 with greatest sensitivity to age at 50% maturity. A preliminary sensitivity removing all catch data north of Barrenjoey Point resulted in a depletion of 17%, but the resulting estimate of mortality was unrealistically low. This sensitivity was repeated with mortality fixed at 0.6, corresponding to the fixed value for mortality used in the 2008 assessment which resulted in a 2018 depletion of 39%. A balanced sensitivity with winter rather than summer spawning produced very similar results to the agreed base case with summer spawning.

Changes to the 2009 stock assessment include: separating length frequencies into onboard and port collected components, with a joint selectivity pattern estimated; weighting length frequencies by shots and trips rather than fish measured; and using the latest agreed best practice tuning method. The updated assessment is remarkably consistent with the results from the 2009 assessment, despite an additional 8 years of data, improvements to data processing and modifications to Stock Synthesis.

15.2 Introduction

15.2.1 *The fishery*

School whiting (*Sillago flindersi*) occur in the eastern regions of the SESSF and Bass Strait (zones 10, 20, 30, 60 and 91) and are commonly found on sandy substrates to depths of about 60m, and sometimes as deep as 150m. School whiting are benthic feeders and they mainly spawn during summer in the southern parts of their range, but with some evidence of spawning in the spring, winter and possibly all year round in the northern parts of their range. They grow rapidly, reach a maximum age of about nine years and become sexually mature at about two years of age.

In the SESSF, full recruitment to the fishery occurs at around three years of age. Selectivity of 50% is only achieved for three year old fish for the Danish seine fishery and the otter trawl fishery. Except for the NSW Danish seine fleet, selectivity for two year olds is less than 20% and for one year olds is less than 2%. The majority of the catch from 1947-1995 has been taken using Danish seine (mainly in zone 60 of the SESSF - Bass Strait) although the fraction of the catch taken by otter trawl has increased recently, and averaged more than 65% of the total catch from 1998-2010 and around 50% of the total catch since 2011. In contrast to the Danish seine catches, catches by otter trawl occur predominantly in SESSF zone 10, with most of this catch taken by state registered trawlers. Much of the school whiting caught by the Lakes Entrance Danish seine fleet since 1993 has been sent to an export market, although issues with quality of whiting caught in the summer months have reduced catches for the export market during this time.

Annual catches (landings and discards) of school whiting used in the 2009 preliminary assessment are shown in Table 15.1 and also in Figure 15.1 (separated by fleet) and Figure 15.2 (separated by jurisdiction). Large catches of school whiting were first taken in the 1980s (Smith, 1994) and catches increased to over 2,000 t in 1986, with a further four years with catch totals over 2,000 t up until 1995. Catches have remained over 1,200 t since 1986, with the peaks in catches generally reducing since the 1990s. Catches since 2008 have generally been between 1,200 and 1,500 t. Discard percentages are variable and appear market driven. From 1986-1996, more than 50% of the catch was taken by Commonwealth registered vessels, dropping to around 35% in the period 1997-2013 and then increasing back to around 50% since 2014. Catches of school whiting taken by state registered vessels comprised more than 50% of the total catch for the period 1997-2013 and have varied between 40% and 50% since 2014 (Figure 15.2).

The Commonwealth TAC for calendar years 2005 and 2006 was 1,500 t and in 2007 this was reduced to 750 t, maintained at 750 t in 2008 and increased to 1125 t in 2009. Since 2009 the Commonwealth TAC has varied between 600 and 1,000 t. The total landed catch (state and Commonwealth) has averaged 1,350 t since 2004, ranging between 1,200 t and just over 1,500 t. In the period 1994-2003, the total landed catch averaged over 1,700 t. The total state catch has averaged around 750 t since 2008, with an average of around 1,000 t in the decade 1998-2007.

15.2.2 *Stock Structure*

School whiting is assumed to be a single stock off the east coast of Australia and in Bass Strait, which is largely encompassed by the SESSF but does continue further north above Barrenjoey Point to Ballina. Stout whiting (*Sillago robusta*) is caught off northern New South Wales and the range of these two species overlaps between Ballina and Clarence River, with the northern limit for school whiting at Ballina. NSW catches of stout whiting and school whiting were split equally between the two whiting species in this region where they both occur.

Dixon *et al.* (1986, 1987) report a discontinuity in the relatedness between samples observed between Forster and Coffs Harbour, which may indicate some degree of separation between the fish from northern and southern NSW. However, the genetic techniques used in this work had little genetic variation and hence low power and this was combined with low sample sizes and possible non-representative sampling (A, Moore, pers. comm.). While this may indicate a possible location to split stocks genetically, it remains unconfirmed using modern techniques. This species would benefit greatly from a new study that uses modern molecular markers and representative sampling. Both the resolution of modern markers and the analysis techniques have increased dramatically the late 1980s. Modern markers and a new study would help to clarify the population structure in this species (A, Moore, pers. comm.).

15.2.3 *Previous assessments*

A full stock assessment for school whiting was last performed in 2009 using data up to 2008 (Day 2009). This assessment was an update of the 2008 assessment (Day 2008b), which in turn extended the 2007 assessment (Day 2007). There were some earlier stock assessments for school whiting, using limited data (Cui *et al*. 2004, Punt 1999).
Given a lack of reliable age- and length-composition data, the 2004 assessment (Cui *et al*. 2004) just used data from the Commonwealth logbook, and ignored catches taken under state jurisdictions and all catches before 1991. As a result, this assessment was only able to give information about biomass levels relative to 1991. Cui *et al*. (2004) looked at the probabilities of falling below the 1991 spawning biomass and half the 1991 spawning biomass for 5 different levels of future catch and predicted large recruitments in 2002 and 2003, albeit with high uncertainty. As a result the 2003 estimate of spawning biomass was higher than the 1991 spawning biomass, but was also highly uncertain.

The 2007 stock assessment (Day 2007) used much more data than the earlier assessments, including catch data from 1947-2006, conditional age-at-length data, length data, discards, ageing error and estimated the growth parameters within the assessment. This assessment estimated a 2008 spawning stock biomass of 35% of unfished stock biomass, but warned that there was some uncertainty about the status of the stock and that with a short lived species this estimate is sensitive to estimates of recruitment. This assessment showed that three out of the last seven recruitment events were above average. This resulted in a 2008 RBC of 904 t under the 20:40:48 control rule, with a corresponding long term RBC of 1,685 t.

The 2008 stock assessment (Day 2008b) incorporated additional data for 2007 and also incorporated a number of revisions to both sample sizes and the distributions of length frequencies for the Danish seine and the otter trawl fleets in the period 1994-2006, due to improvements in the data extraction process. This assessment estimated a 2009 spawning stock biomass of 82% of unfished stock biomass, and again warned that there was some uncertainty about the status of the stock and that with a short lived species this estimate is sensitive to estimates of recruitment. The 2008 assessment showed that six of the last seven estimated recruitment events were above average and warned that "if these recent strong recruitment events are not supported by future data, the evidence for a recent strong recovery in the stock may need to be moderated". This resulted in a 2009 RBC of 3,785 t under the 20:35:48 control rule, with a corresponding long term RBC of 2,070 t.

The 2009 stock assessment (Day 2009) incorporated a number of changes, including: (a) revised historical catch, length and age data for the period 1994-2007, (b) the addition of updated length frequencies, catches and catch-rates for data collected in 2008, (c) the estimation of recruitment up to 3 years before the most recent data and (d) the estimation of the natural mortality parameter, M. This assessment estimated a 2010 spawning stock biomass of 50% of unfished stock biomass. The 2009 assessment showed that four of the last seven estimated recruitment events were above average, in contrast to the 2008 assessment. This resulted in a 2010 RBC of 1,723 t under the 20:35:48 control rule, with a corresponding long term RBC of 1,660 t.

Due to the variation in depletion results produced by assessment reports between 2007 and 2009, fixed catch scenarios were examined after the 2009 stock assessment (Day 2010, Day 2011) exploring projections with fixed long term catches ranging between 1,400 t and 2,000 t and estimating the probability of falling below the limit Biomass (B_{20}) for these fixed catch scenarios, and for a range of sensitivities for some of the key fixed parameters. This gave support to an RBC of around 1,660 t, the long term RBC from the 2009 assessment. Recruitment retrospectives were examined (Day 2010) to explore the reliability of the most recently estimated recruitment events and to test the age at which useful recruitment data can be estimated. This also suggested changes in recent recruitment estimates were linked to changes in other parameters fitted by Stock Synthesis, revisions to historical data sets and possible non-representative sampling in some years. Other issues were explored (Day 2011) including unsuccessfully searching for correlations of spawning biomass with biological parameters, a brief assessment update using data to 2010 and running this assessment update using Commonwealth data only.

15.2.4 *Modifications to the previous assessments*

The 2017 assessment uses Stock Synthesis version SS-V3.30.08.03, (Methot et al 2017), updated from version SS-V3.03a (Methot 2009) that was used in the 2009 assessment. New catch, discard, length and conditional age at-length data is available from the eight year period from 2009-2016. Conditional age-at-length data used in the 2009 assessment was based on ageing of whole otoliths in the period 1994-2006 and sectioned otoliths from 2007 and 2008. The ageing data from whole otoliths from 1994-2006 was not used in the 2017 assessment due to differences in the age range obtained from readings of sectioned and whole otoliths. These data were replaced by age-at-length data obtained by sectioning and re-ageing a selection of the available historical otoliths. This resulted in the 2017 assessment only using age data from sectioned otoliths, using newly read conditional age-at-length data for the period 1991-2006, the previous data from sectioned otoliths from 2007-2008 and new conditional age-at-length data for the period 2009-2016. As a consequence, the maximum age (or the age for the plus group) changed from six to nine years. In addition to these new and updated data, there is an updated standardised CPUE series for the Commonwealth Danish seine fleet with eight additional data points, a new standardised CPUE series for the Commonwealth trawl fleet from 1995 and updated estimates for the ageing error matrix (using sectioned otoliths only).

15.2.4.1 Data-related issues

1. Length-frequency data are included separately for onboard data by fleet, in addition to the port based length frequency data which were the only length-frequency data used in the 2009 assessment. Port and onboard fleets share a single selectivity pattern.
2. Length frequency data are weighted by shot or trip numbers rather than numbers of fish measured. A cap of 100 trips and 200 shots was used to set an upper limit on the sample size, although the limit on trip numbers was never exceeded.
3. The longest catch-rate time series is from the Victorian Danish seine fleet (Haddon and Sporcic, 2017) from 1986-2016.
4. A new catch rate time series is included for the trawl fleet (Haddon and Sporcic, 2017) using Commonwealth logbook data from 1995-2016.

5. State catches have been added to catches from the appropriate fleets with some revision of the historical NSW state catch.
6. The ageing error matrix has been updated (using sectioned otoliths only).
7. Catch, discard, length-composition, age-at-length, and catch rate data have been added for the period 2009-2016.

15.2.4.2 Model-related issues

1. Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with all four growth parameters estimated separately, based primarily on the age-at-length data from fish that were measured and aged from extracted otoliths. In the 2009 assessment, it was only possible to estimate three of the four growth parameters, with K fixed to get a reasonable growth curve and to avoid very high correlations between K and L_{max}.
2. Natural mortality, M, is estimated within the model.
3. Recruitment residuals are estimated from 1981-2013, with the last recruitment event estimated three years before the most recent available data.
4. An updated tuning procedure has been used to balance the weighting of each of the data sources that contribute to the overall likelihood function, using Francis weighting for length and age data (Francis, 2011), balancing the CPUE series within Stock Synthesis, and improvements to the recruitment bias ramp adjustment.

The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be contributing to changes in the assessment outcome was conducted (Day, 2017).

15.3 Methods

15.3.1 *The data and model inputs*

15.3.1.1 Biological parameters

A single-sex model (i.e. both sexes combined) was used, as the length composition data for school whiting are not available by sex.

Age-at-length data was used as an input, and all four parameters of the von Bertalanffy growth equation were estimated within the model fitting procedure. This is more appropriate than pre-specifying these values because it accounts for the impact of gear selectivity on the age-at-length data collected from the fishery and the impact of ageing error.

As in the 2009 assessment, M was able to be estimated within the model. The base-case value for the steepness of the stock-recruitment relationship, h, is 0.75.

School whiting become sexually mature at a length of about 16 cm, when the fish are around two years of age. Fecundity is assumed to be proportional to spawning biomass. The parameters of the length-weight relationship are obtained from Klaer and Thomson (2006) (a=1.32 × 10^{-5}, b=2.93).

15.3.1.2 Fleets

As was the case in the 2009 assessment, this assessment for school whiting is based on three fleets: two Danish seine fleets (with NSW and Victorian fleets treated separately) and a single otter trawl fleet. Time-invariant logistic selectivity is assumed for all three fleets.

1. Victorian Danish seine – Danish seine based around Lakes Entrance in eastern Victoria and Bass Strait and Eastern Tasmania (1947 – 2016). Length frequency data are available for this fleet from Victorian Fisheries in 1991 and from the Integrated Scientific Monitoring Program (ISMP) records in the years 1994-2008. This fleet largely comprises catches from Commonwealth registered Danish seine vessels, but also includes small catches from Victorian and Tasmanian Danish seine vessels.
2. Otter trawl – otter trawlers from NSW, eastern Victoria and Bass Strait, including both Commonwealth and state registered vessels (1947 – 2016). Length frequency data are available for this fleet for two years from the Sydney Fish Market, 1983 and 1988, and from ISMP records from 1997-2008. In addition, there are length frequency data from 1971 and 1974 for otter trawl from the northern limit of the school whiting range.
3. NSW Danish seine – Danish seine fleet operating in state waters in NSW (1957 – 1994, 2010-2016). Length frequency data are available for this fleet from the Sydney Fish Market from 1983 -1989. This fleet was not operating when the 2009 assessment was conducted but has become active again since 2010.

In addition to these fleets, an ocean prawn trawl fleet operates in NSW state waters, largely north of Barrenjoey Point. Given the absence of available length data for this fleet, making it impossible to estimate selectivity, and the difficulty separating historical catches for this fleet prior to 1998, catches from this fleet are attributed to the otter trawl fleet. If length frequency data from this fleet can be obtained in the future, it may be worth reviewing this decision. Similarly length frequency data from the more recent NSW Danish seine catches, since 2010, would be useful to compare to the only length frequency data available from this fleet from 1983-1989.

Catches from the Victorian Danish seine fleet and the otter trawl fleet include catches from both Commonwealth and state registered vessels. Allocating the catch data, which is provided separately by jurisdiction, into catch by fleet requires careful processing of the raw data, with rules to allocate this catch by fleet varying over both time and data source.

15.3.1.3 Landed catches

The model uses a calendar year for all catch data. Landings data come from a number of sources. Early Victorian school whiting catches are available from 1947-1978 (Wankowski, 1983) and later Victorian state catches, from 1979-2006, were provided by Matt Koopman. Information enabling these Victorian state catches to be separated by fleet is not available so it is assumed that 3% of these catches are from the otter trawl fleet and 97% are from Danish seine for the whole period. Matt Koopman supplied a catch history separated into state and Commonwealth catches for the period 1957-2006. None of these catches are separated by fleet.

The original data for the NSW component of this catch for the period from 1957-1992 is from Pease and Grinberg (1995). Corrections were made to these catches to remove the stout whiting component from the catch (Kevin Rowling, pers. comm.), with these corrections based on how far north the catch was landed along the NSW coast. Due to limited availability of catch data in the period 1957-1984, 66% of the NSW catches reported by Pease and Grinberg were assigned to school whiting in this period. These adjusted catches of school whiting were incorporated into the NSW state catch history initially provided by Matt Koopman.

The NSW state catch history from 1985 onwards was further revised in 2017 (Karina Hall, pers. comm.) to improve the estimates of school whiting catches, by excluding the best estimates of stout whiting catches in specific northern fishing zones in NSW state waters during this period. The proportion of whiting catch comprising stout whiting increases the further north the catch is taken.

After all of these adjustments to the NSW catch total are completed, the total NSW state catch was then allocated in the ratio of 97% to the otter trawl fleet and 3% to the NSW Danish seine fleet from 1957-1994. From 1995 to 2009 all of the NSW state catch was assumed to be otter trawl. From 2010 to 2016, the Danish seine component of the NSW state catch is known and the remaining catch is assumed to be otter trawl. The NSW Danish seine catch from 2010 onwards is not publicly available.

Tasmanian state catches are available from 1995-2016 and all of this catch was assigned to the Victorian Danish seine fleet.

Commonwealth catches from 1985-2016 are separated into otter trawl and Danish seine (assumed to be the “Victorian Danish seine” fleet). These data come from the Commonwealth logbook records.

Annual landed catches for the three fleets used in this assessment (Victorian Danish seine, otter trawl and NSW Danish seine) are shown in Figure 15.1 and Table 15.1, with recent NSW Danish seine catches redacted, and with only the total catches listed in Table 15.1 for the period 2010-2016 (catches by fleet are not listed for these years), to maintain confidentiality of NSW Danish seine catches. The same catch history separated into state and Commonwealth components is shown in Figure 15.2.

This catch history is slightly modified from the catch history presented at the September 2017 SERAG meeting (Day 2017). Issues were discovered in both the NSW state catch data and the Commonwealth catch data with catches misreported on both sides of the line at Barrenjoey Point, and corrections were made to these data sources where possible. In addition to these changes, the Commonwealth catch history between 2003 and 2007 was updated in the preliminary base case (Day 2017) using data provided by AFMA. Updates to the Victorian Inshore Trawl component of this catch were inconsistent in the AFMA database with the data used in 2009, which was compiled by Neil Klaer (SEF2 VIC catches). Discrepancies between the two data sources could not be resolved. As the data compiled by Neil Klaer was processed closer to the collection of the data, a decision was made to use this data source. The maximum difference in any one year between these two sources of data was 50 t in 2004, with a combined difference of 34 t over a five year period, so the effect of this change was minor.

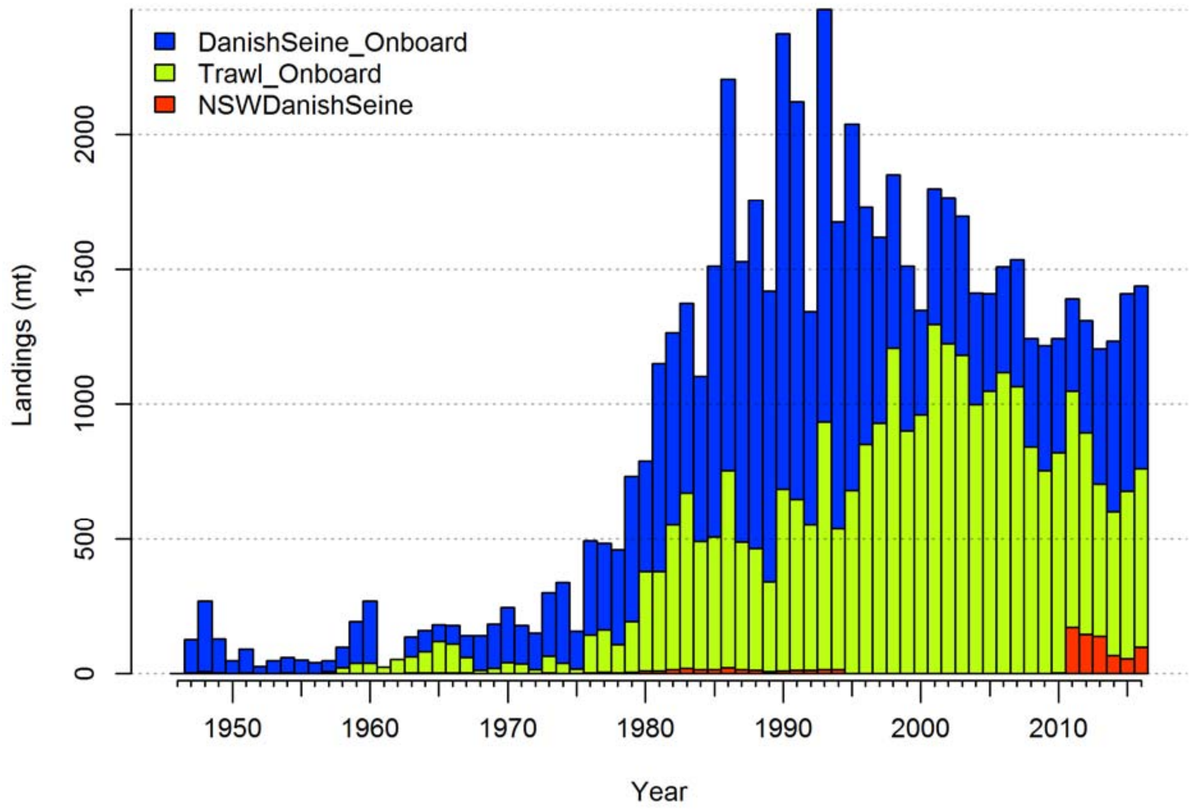

Figure 15.1. Total landed catch (tonnes) of school whiting by fleet (stacked) from 1947-2016. Recent NSW Danish seine catches are not publicly available.

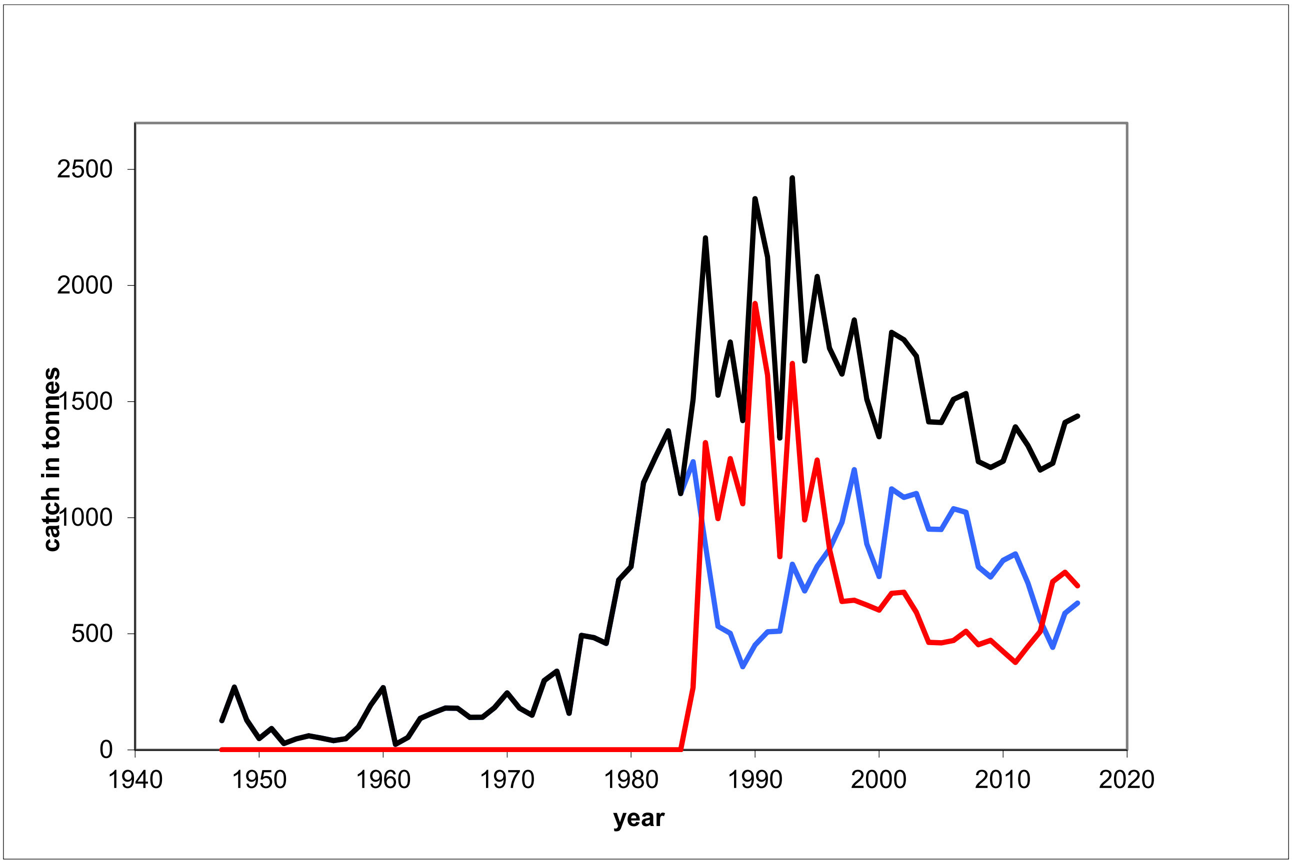

Figure 15.2. Total landed catch of school whiting in the SESSF from 1947-2016 (black line with circles) and this same catch separated into jurisdiction with state catches (blue) and Commonwealth catches (red). The Commonwealth catch was larger than the state catch in the periods 1987-1996 and 2014-2015. The state catches (blue) comprise the whole catch until 1985. The Commonwealth catch starts in 1985.

Table 15.1. Total retained catches (tonnes) of school whiting per fleet for calendar years from 1947-2009. Only the combined total for all fleets is shown for 2010-2016.

Year	Vic DS	Otter trawl	NSW DS	Total	Year	Vic DS	Otter trawl	NSW DS	Total
1947	122	4	0	126	1982	714	535	16	1264
1948	262	8	0	270	1983	705	650	19	1374
1949	125	4	0	129	1984	614	476	14	1104
1950	47	1	0	49	1985	1005	492	14	1511
1951	89	3	0	92	1986	1451	732	21	2205
1952	26	1	0	27	1987	1041	473	14	1528
1953	46	1	0	47	1988	1293	451	13	1756
1954	59	2	0	61	1989	1079	331	8	1418
1955	49	2	0	51	1990	1691	673	10	2375
1956	39	1	0	40	1991	1477	634	12	2123
1957	41	7	0	48	1992	791	540	12	1343
1958	76	22	1	98	1993	1529	919	16	2464
1959	154	38	1	193	1994	1138	521	16	1675
1960	230	37	1	268	1995	1359	680	0	2039
1961	0	23	1	24	1996	880	850	0	1731
1962	0	52	2	54	1997	688	931	0	1619
1963	73	61	2	136	1998	645	1207	0	1852
1964	78	79	2	159	1999	610	901	0	1511
1965	59	117	4	180	2000	388	961	0	1349
1966	69	107	3	179	2001	502	1296	0	1799
1967	81	57	2	140	2002	544	1223	0	1767
1968	128	12	0	140	2003	515	1180	0	1696
1969	164	18	0	183	2004	415	998	0	1413
1970	204	40	1	245	2005	362	1047	0	1410
1971	143	36	1	180	2006	393	1117	0	1510
1972	135	14	0	149	2007	469	1065	0	1534
1973	233	64	2	299	2008	400	842	0	1242
1974	301	37	1	338	2009	463	754	0	1216
1975	139	17	0	157	2010				1243
1976	351	138	4	493	2011				1391
1977	322	157	5	483	2012				1310
1978	352	104	3	459	2013				1205
1979	538	188	5	732	2014				1234
1980	412	367	11	789	2015				1410
1981	772	368	11	1151	2016				1438

The state catch is a significant proportion of the total catch for school whiting (Figure 15.2) From 1986-1996 the state catch averaged around 30% of the total catch, but from 1997-2013, the state catch increased and the Commonwealth catch decreased and as a result the state catch averaged around 60% of the total catch in this period. Since 2014, the Commonwealth catch has increased and the state catch has decreased, with the Commonwealth catch averaging just over 50% in this period. The difference between catches in state and Commonwealth jurisdictions does not affect this assessment directly, but it does affect how catches are allocated to the different fleets, and it will have an impact on the allocation of the RBC.

The NSW trawl fleet averages around 85% of the total state catches in the period 1986-2016. The Commonwealth catch starts in 1985 and the Victorian Danish seine fleet comprises around 85% of the Commonwealth catch since 1986. The Commonwealth catch was less than the state catch in the period 1997-2013.

In order to calculate the Recommended Biological Catch (RBC) for 2018, it is necessary to either estimate the calendar year catch for 2017, or to make an assumption about this catch. Without any other information, the 2017 catch for each fleet was assumed to be the same as the 2016 catch. The recent TAC history, which only applies to the Commonwealth component of the catch, is listed in Table 15.2.

Table 15.2. Total allowable catch (tonnes) from 1993 to 2017.

Year	TAC Agreed
1993	2000
1994	2000
1995	2000
1996	2000
1997	2000
1998	2000
1999	1500
2000	1500
2001	1500
2002	1500
2003	1500
2004	1500
2005	1500
2006	1500
2007	734
2008	750
2009	1125
2010	844
2011	641
2012	641
2013	809
2014	809
2015	747
2016	868
2017	986

15.3.1.4 Discard rates

Information on the discard proportions of school whiting by fleet is available from the ISMP for 1994-2016. This program was run by PIRVic from 1992-2006 and by AFMA from 2007. These data are summarised in Table 15.3. Discard proportions vary amongst years and have been as high as 40% (in 1998). Members of the fishing industry have indicated that discarding of small school whiting can vary rapidly in response to demands from the export market.

Table 15.3. Discard proportions for Vic Danish seine and otter trawl fleets from 1994 to 2016 with sample sizes for each data point. Entries in grey indicate data that are not used either due to small sample size (less than 10 samples) or because the value is too close to zero (less than 0.02).

Year	Vic DS discard proportion	n	Trawl discard proportion	n
1994	0.0564	150	1	3
1995	0.0024	102	1	1
1996			0.2705	17
1997			0.0540	10
1998			0.3986	15
1999	0.1199	17	0.1740	37
2000			0.1049	45
2001	0.0753	28	0.1260	120
2002			0.1009	98
2003	0.0088	36	0.0888	127
2004	0.0000	19	0.0637	98
2005			0.1928	93
2006			0.0456	71
2007			0.0412	4
2008				
2009			0.0027	15
2010	0.0033	22	0.0609	21
2011	0.0575	35	0.0387	9
2012	0.0278	17		
2013	0.0084	24	0.4664	6
2014	0.0811	35	0.1187	4
2015	0.0311	51	0.2592	39
2016	0.0462	58	0.0580	7

Discard practices can be variable between years for reasons that are difficult to model, with some years having very low discard rates and others having considerable discard rates. Without a mechanism to explain these years of very low discarding, discarding practices are assumed to be constant through time. Given the coefficient of variation associated with discard measurements, using years with very low discard proportions forces the model to fit very low discard rates to all years, even those when discarding is known to be higher, and underestimates discarding over all years. As a result, years with very low discard proportions (less than 2%) are excluded as inputs to stock synthesis (the greyed figures in the proportion columns in Table 15.3 – all from the Victorian Danish seine fleet) giving more believable estimates of discarding in general. Note that any discard estimate coming from a sample size of less than 10 is also excluded as it is likely to be unrepresentative (greyed figures in the sample size columns in Table 15.3 – all from the otter trawl fleet). Note that this excludes some years which appear to have very high discarding (e.g. 47% in trawl in 2013 from 6 samples, or 100%

discarding with 3 samples or fewer in 1994 and 1995), so both very large and very small outliers are excluded in this process.

Observations were then used to estimate discard rates, for each fleet (Figure 15.3) and hence discarded catches for each fleet (Figure 15.4, Figure 15.5), with estimated discard rates of around 5% for the Danish seine fleet and around 10% for the trawl fleet.

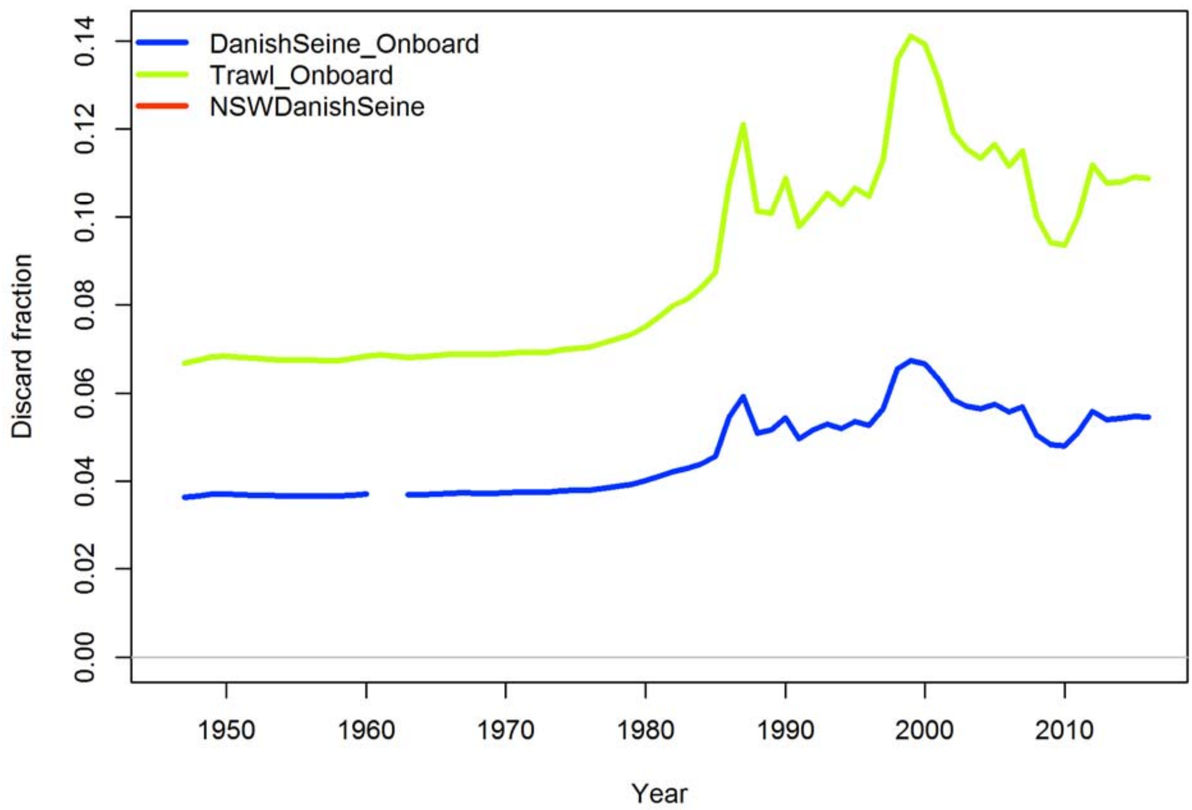

Figure 15.3. Model estimates of discard fractions by fleet, Danish seine (blue) and otter trawl (green).

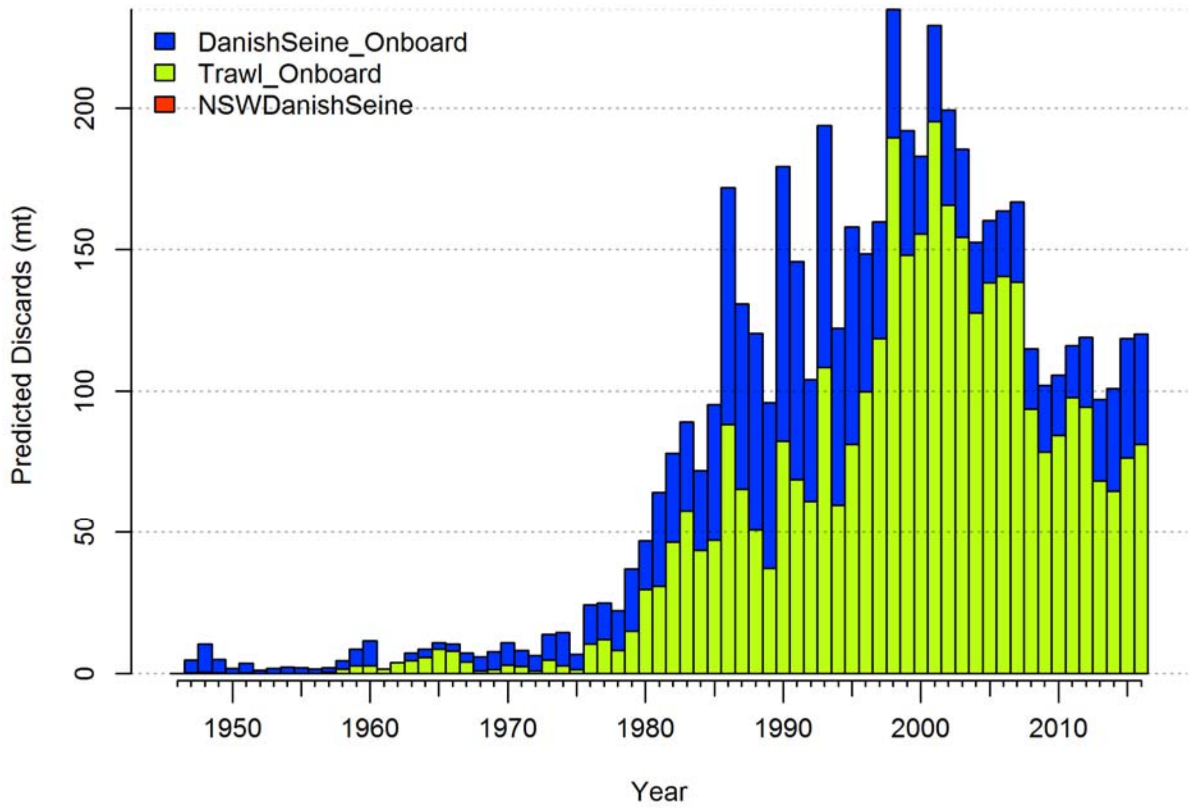

Figure 15.4. Estimated discards (tonnes, stacked) of school whiting in the SESSF from 1947-2016, Danish seine (blue) and otter trawl (green).

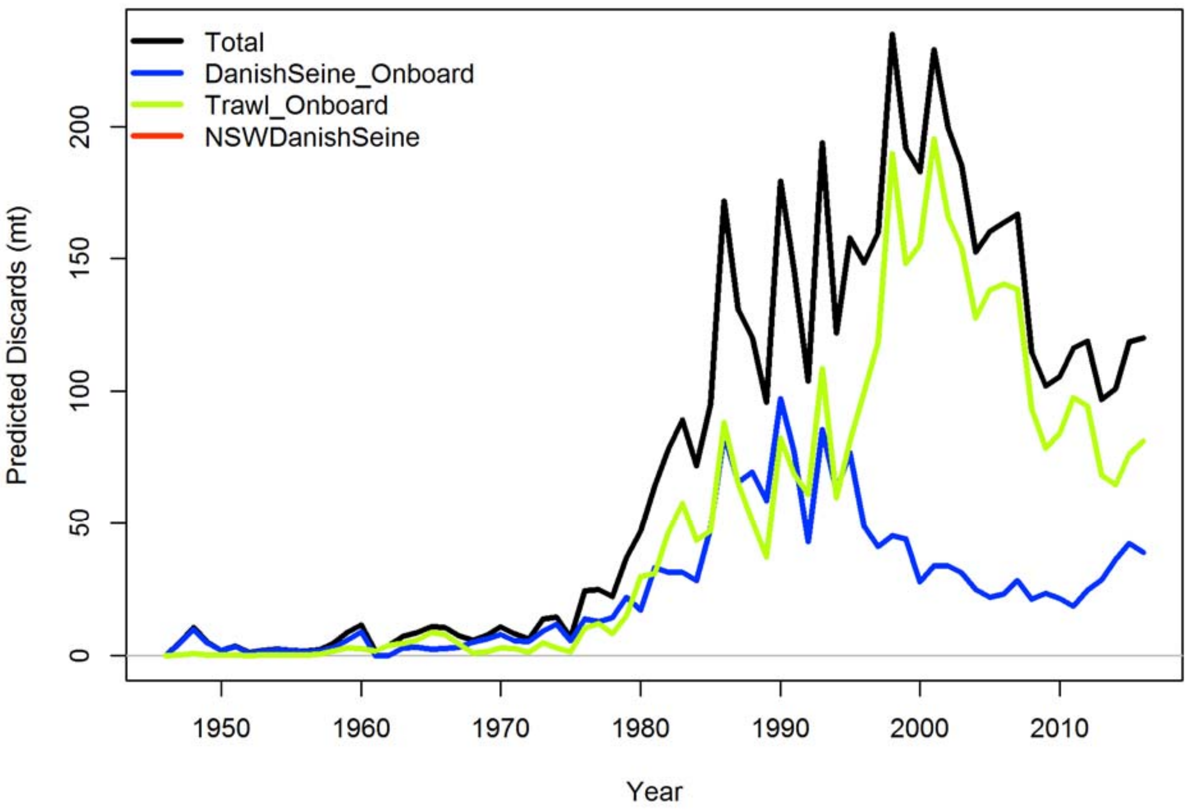

Figure 15.5. Estimated discards (tonnes) of school whiting in the SESSF from 1947-2016, Danish seine (blue), otter trawl (green), combined total (black).

15.3.1.5 Catch rate indices

Catch and effort data from the SEF1 logbook database were standardised using GLMs to obtain indices of relative abundance (Haddon and Sporcic, 2017; Table 15.4) from the period 1986-2016 for the Victorian Danish seine fleet and from 1995-2016 for the trawl fleet.

Table 15.4. Standardised catch rate indices and coefficient of variation (Haddon and Sporcic, 2017) for the Victorian Danish seine fleet and the trawl fleet for school whiting. The coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Haddon and Sporcic, 2017).

Year	Catch rate Vic DS	cv (DS)	Catch rate trawl	cv c.v. (TW)
1986	1.1337	0.176		
1987	1.2540	0.176		
1988	1.5934	0.176		
1989	1.0596	0.176		
1990	1.6333	0.176		
1991	1.4501	0.176		
1992	1.0455	0.176		
1993	1.4916	0.176		
1994	0.8731	0.176		
1995	1.1067	0.176	1.2167	0.180
1996	0.7274	0.176	1.3600	0.180
1997	0.5536	0.176	0.9395	0.180
1998	0.5340	0.176	0.9470	0.180
1999	0.6047	0.176	1.1483	0.180
2000	0.6335	0.176	1.1447	0.180
2001	0.8824	0.176	1.2643	0.180
2002	0.8722	0.176	1.0444	0.180
2003	0.9129	0.176	0.9874	0.180
2004	0.8366	0.176	0.7679	0.180
2005	0.9377	0.176	1.0794	0.180
2006	0.8391	0.176	1.4908	0.180
2007	1.1093	0.176	1.4509	0.180
2008	1.0978	0.176	0.9456	0.180
2009	1.1732	0.176	0.8113	0.180
2010	1.0369	0.176	0.9782	0.180
2011	0.8365	0.176	0.8242	0.180
2012	0.9046	0.176	0.6116	0.180
2013	0.9210	0.176	0.5563	0.180
2014	1.0175	0.176	0.7577	0.180
2015	0.9727	0.176	0.6817	0.180
2016	0.9555	0.176	0.9918	0.180

The restrictions used in selecting data for analysis for Danish seine fleet were: (a) vessels had to have been in the fishery for three or more years, (b) the catch rate had to be larger than zero, (c) catches in zone 60 only (d) catches in less than 100m depth and (e) effort is considered as catch per shot rather than as catch per hour, to allow for missing records of total time for each shot for data early in the fishery.

The restrictions used in selecting data for analysis for the trawl fleet seine were: (a) vessels had to have been in the fishery for three or more years, (b) the catch rate had to be larger than zero, (c) catches in zones 10, 20 and 91 only (d) catches in less than 150m depth and (e) effort is considered as catch per hour. Catches recorded in zone 91 are apparently caught in state waters, but it appears there were issues with location recorded for some shots and these either represent shots which were actually in zone 10 or at least record school whiting caught by Commonwealth registered vessels in zone 91. In either case the catch rate data should be informative so records from zone 91 were included.

15.3.1.6 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 (Day, 2009). For the 2017 assessment, port and onboard length composition data are both used separately, with the gear selectivity estimated jointly from both port and onboard data from each fleet (Victorian Danish seine and otter trawl). The 2009 assessment weighted length samples by the number of fish measured. For onboard data, the number of shots, 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 can be used instead. In the 2017 assessment, the initial sample size associated with each length frequency in the assessment is the number of shots or trips.

Length data were excluded for years with less than 100 individual fish measured, as this was considered to be unrepresentative (with excluded data listed in grey in Table 15.5 and Table 15.6). Sample sizes for retained length frequencies, including both the number of individuals measured and number of trips (inferred numbers of trips listed in blue in Table 15.6) are listed in Table 15.6 for each fleet and year for the period 1983-2016 and for discarded length frequencies in Table 15.5 for the period 1994-2016. For years and gear types where the number of trips is not available (port measurements for NSW Danish seine and NSW trawl fleet between 1983-1989 and one year of data from the Victorian Danish seine fleet in 1991), the number of trips is inferred from the number of fish measured per trip for years where this data is available for each gear type.

Length composition information for the retained component of the catch by the Victorian Danish seine fleet is available from port sampling for the period 1994-2016 and from onboard sampling from 1998-2016. Onboard data collected by the ISMP were used to calculate the length frequency of the discarded component of the catch from this fleet for five years only in this same period. An additional year (1991) of Victorian Fisheries length frequency data for the retained catch from the Victorian Danish seine fleet was also used (Anonymous, 1992).

Length composition information for the retained component of the catch by the Commonwealth trawl fleet is available from port and onboard sampling for 1998-2016 and in 1983 and 1988 from NSW state otter trawl sampled in port (Kevin Rowling, pers. comm. 2006). Onboard data collected by the ISMP were used to calculate the length frequency of the discarded component of the catch for six years only from 1998-2016.

Length composition information for the retained component of the catch by the NSW Danish seine fleet is available from Sydney Fish Market measurements for the period 1983-1989.

Table 15.5. Number of port and onboard discarded lengths and number of shots for length frequencies included in the base case assessment by fleet 1994-2016. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured).

year	fleet Vic DS onboard # fish	(discard) trawl onboard # fish	Vic DS onboard # shots	trawl onboard # shots
1994	4720		40	
1995	199		2	
1998		133		1
1999	292		16	
2001	160	251	4	9
2002		81		2
2003		532		7
2004		155		5
2005		205		6
2009		14		2
2010	1		1	
2011	5		2	
2012	95		8	
2014	202		23	
2015	46	178	3	7
2016	277	18	15	1

Table 15.6. Number of port and onboard retained lengths and number of shots or trips for length frequencies included in the base case assessment by fleet 1983-2016. The number of trips from early NSW data (in blue) is inferred from numbers of fish measured. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured).

year	**fleet**	**(retained)**								
	Vic DS onboard	**Vic DS port**	**trawl onboard**	**trawl port**	**NSW DS port**	**Vic DS onboard**	**Vic DS port**	**trawl onboard**	**trawl port**	**NSW DS port**
	# fish	**# fish**	**# fish**	**# fish**	**# fish**	**# shots**	**# trips**	**# shots**	**# trips**	**# trips**
1983				436	2790				3	31
1984					1275					14
1985					370					4
1986					2046					23
1987					449					5
1988				500	260				3	3
1989					220					2
1991		2026					23			
1994		527					2			
1995		3511					66			
1996		2390					23			
1997		4190					46			
1998	233	5708	52	250		3	64	1	2	
1999	861	1588	153	2547		23	17	3	25	
2000	462	776	253	45		7	10	3	1	
2001	453	858	1018	6340		10	11	17	61	
2002	743	727	2553	1726		8	10	23	28	
2003	1836	315	3074	1615		16	3	31	16	
2004	767	1147	2757	11019		7	9	24	27	
2005	2425	1003	2392	7609		17	7	25	17	
2006	1333		1127	16866		11		10	63	
2007	242	2558		1056		1	14		5	
2008	67	894	52			4	7	2		
2009	335	880	20	288		5	15	1	4	
2010	558	1179	481			19	20	3		
2011	1607	1222	133	435		27	40	2	1	
2012	379	1263	40	46		11	44	1	1	
2013	1488	1488	278	181		21	41	5	3	
2014	861	1704	280	708		35	54	2	6	
2015	1841	2776	1265	1086		31	46	22	8	
2016	2157	2456	122	94		41	39	2	1	

15.3.1.7 Age composition data

Age-at-length measurements, based on sectioned otoliths provided by Kyne Krusic-Golub of Fish Ageing Services Pty Ltd, are available from 1991-2016 for the Victorian Danish seine fleet and from 2001-2015 for the otter trawl fleet. These data replaced the age-at-length data up to 2006 based on reading whole otoliths used in the 2009 assessment. An estimate of the standard deviation of age-reading error was calculated by André Punt (pers. comm., 2017) using data supplied by Kyne Krusic-Golub and a variant of the method of Richards *et al*. (1992) (Table 15.7).

Age-at-length measurements, based on sectioned otoliths, provided by Fish Ageing Services, were available for the years 1991-1996, 1998, 2000-2016 for the Danish seine fleet; 2001-2004, 2009-2015 for the otter trawl fleet. The Victorian Danish seine age-at-length data from the year 2000 listed all fish in the oldest age group and was excluded as a result. Further investigation revealed a transcription error in processing this data with length measurements recorded in place of age readings, so this year of age data can be corrected and incorporated in a future assessment.

Table 15.7. Standard deviation of age reading error (A Punt pers. comm. 2017).

Age	sd
0.5	0.190385
1.5	0.190385
2.5	0.264961
3.5	0.292396
4.5	0.302489
5.5	0.306201
6.5	0.307567
7.5	0.308070
8.5	0.308255
9.5	0.308323

Table 15.8. Number of age-length otolith samples included in the base case assessment by fleet 1991-2016.

Year	Fleet		
	Vic DS	Trawl	Total
1991	100		100
1992	419		419
1993	309		309
1994	430		430
1995	296		296
1996	278		278
1998	416		416
2000	156		156
2001	309	100	409
2002	233	250	483
2003	284	189	473
2004	370	76	446
2005	390		390
2006	128		128
2007	98		98
2008	478		478
2009	291	128	419
2010	564	50	614
2011	520	56	576
2012	437	113	550
2013	128	38	166
2014	646	134	780
2015	816	347	1163
2016	346		346

Implied age distributions for retained and discarded fish 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 and the age-length relationship. Implied age distributions can be calculated separately for both onboard and port fleets and for the retained and discarded length frequencies and can be calculated from 1998-2016 for the Victorian Danish seine fleet and from 1994-2016 for the otter trawl fleet.

15.3.1.8 Input data summary

The data used in this assessment is summarised in Figure 15.6, indicating which years the various data types were available.

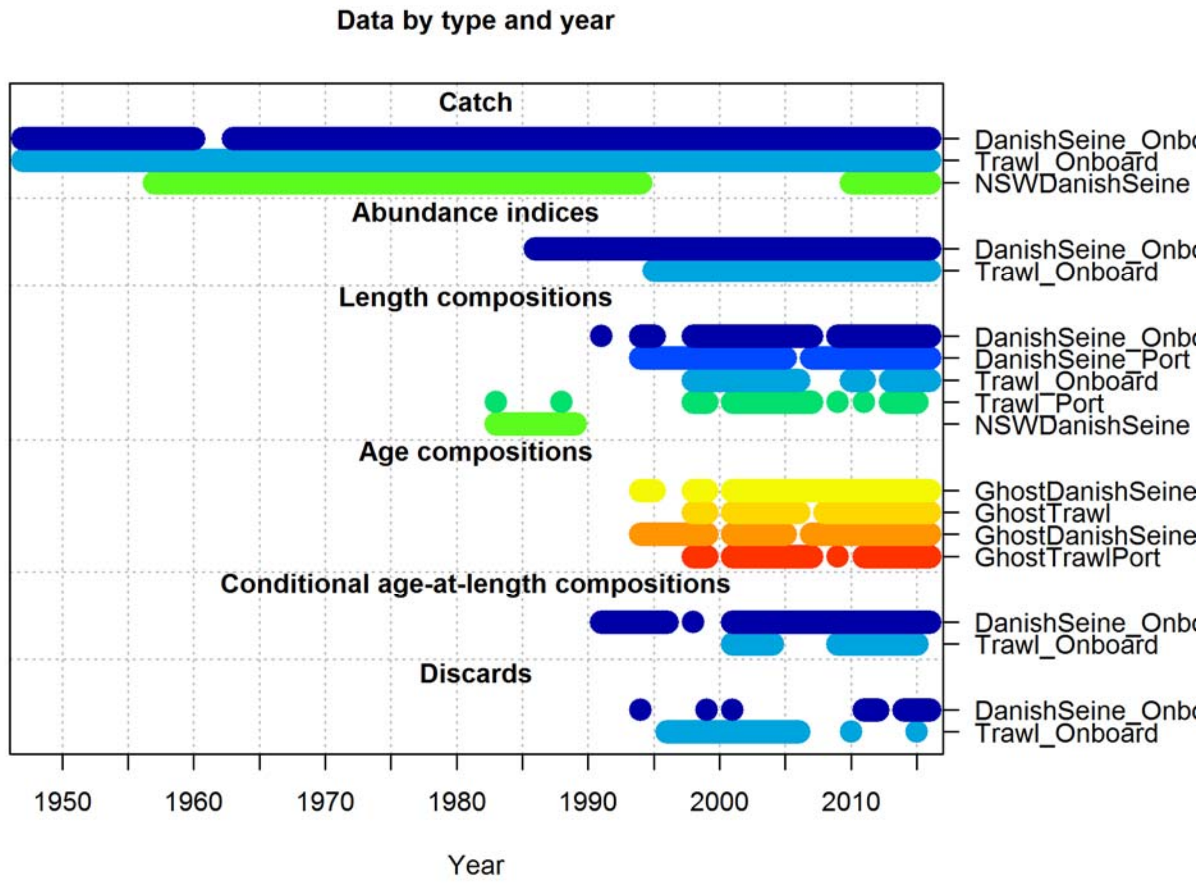

Figure 15.6. Summary of input data used for the school whiting assessment.

15.3.2 *Stock assessment method*

15.3.2.1 Population dynamics model and parameter estimation

A single-sex stock assessment for school whiting was conducted using the software package Stock Synthesis (version SS-V3.30.08.03, Methot *et al*. 2017). 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 school whiting. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS technical documentation (Methot, 2005) and are not reproduced here. Some key features of the base-case model are:

a) School whiting constitute a single stock within the area of the fishery (Smith and Wayte, 2005).

b) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1947. This corresponds to a break in fishing during World War II and, given the facts that the species is short lived and was only lightly exploited prior to World War II, this seems a reasonable assumption.

c) The CVs of the CPUE indices for the Victorian Danish seine and otter trawl fleets were initially set to the root mean squared deviation from a loess fit to the fleet specific indices (Haddon and Sporcic, 2017) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

d) Three fishing fleets are modelled.

e) Selectivity was assumed to vary among fleets, but the selectivity pattern for each separate fleet was modelled as length-specific, logistic and time-invariant. The two parameters of the selectivity function for each fleet were estimated within the assessment.

f) Retention was also defined as a logistic function of length, and the inflection and slope of this function were estimated for the two fleets where discard information was available (Victorian Danish seine and otter trawl). Retention for the NSW Danish seine fleet was implicitly assumed to be independent of length as no length frequency composition data is available on discards for this fleet.

g) The rate of natural mortality, *M*, is assumed to be constant with age and also time-invariant. The value for *M* was estimated within the model in this assessment.

h) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited 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 1981 to 2013. Deviations are not estimated prior to 1981 or after 2013 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.

i) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set equal to 0.35 in the base case. Attempts were made to balance this parameter value to match the standard deviations of estimated recruitment about the stock-recruitment relationship. This resulted in unrealistically low values for σ_r with the model expecting a lower value, so σ_r was fixed at a lower bound (0.35) set for this parameter.

j) A plus-group is modelled at age nine years.

k) Growth of school whiting is assumed to be time-invariant, meaning 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.

l) The sample sizes for length and age frequencies were tuned for each fleet so that the input sample size was approximately equal to the effective sample size calculated by the model. Before this retuning of length frequency data was performed by fleet, any sample sizes with a sample size greater than 100 trips or 200 shots were individually down-weighted to a maximum sample size of 100 and 200 respectively. This is because the appropriate sample size for length frequency data is probably more closely related to the number of shots sampled, rather than the number of fish measured.

15.3.2.2 Relative data weighting

Iterative reweighting of input and output CVs or input and effective sample sizes is an imperfect but objective method for ensuring that the expected variation is comparable to the input. This makes the model internally consistent, although some argue against this approach, particularly if it is believed that the input variance is well measured and potentially accurate. It is not necessarily good to down weight a data series just because the model does not fit it, if in fact, that series is reliably measured. On the other hand, most of the indices we deal with in fisheries underestimate the true variance by only reporting measurement and not process error.

Data series with a large number of individual measurements such as length or weight frequencies tend to overwhelm the combined likelihood value with poor fits to noisy data when fitting is highly partitioned by area, time or fishing method. These misfits to small samples mean that apparently simple series such as a single CPUE might be almost completely ignored in the fitting process. This model behaviour is not optimal, because we know, for example, that the CPUE values are in fact derived from a very large number of observations.

Length compositions were initially weighted using trip and shot numbers, where available, instead of numbers of fish measured and by adopting the Francis weighting method for age and length composition data.

Shot or trip number is not available for all data, especially for some of the early length frequency data. In these cases, the number of trips was inferred from the number of fish measured using the average number of fish per trip for the relevant gear type for years where both data sources were available. The number of trips were also capped at 100 and the number of shots capped at 200. Samples with less than 100 fish measured per year were excluded.

These initial sample sizes, based on shots and trips, are then iteratively reweighted so that the input sample size is equal to the effective sample size calculated by the model using the Francis weighting method.

15.3.2.3 Tuning procedure

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 by the model. In SSv3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. Set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the root mean squared deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis). SSv3.30 then re-balances the relative abundance variances appropriately.

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

2. Adjust the recruitment variance (σ_R) by replacing it with the RMSE (as long as this falls within specified minimum and maxima (0.35 to 0.7)) and iterate to convergence (keep altering the recruitment bias adjustment ramps as predicted by SSv3.30 at the same time).

Finally for the conditional age-at-length and length composition data:

3. Multiply the initial sample sizes by the sample size multipliers for the age composition data using Francis weights (Francis, 2011).

4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data.
5. Repeat steps 2 to 4, until all are converged and stable (proposed changes are < 1%).

This procedure may change in the future after further investigations but constitutes current best practice.

15.3.2.4 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 2006-2016. 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 basis used for assessing stock status or exploitation level for that stock. School whiting is classified as a Tier 1 stock as 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. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2008) determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} respectively, this form of the rule is equivalent to a 20:35:48 (B_{lim}: Inflection point: F_{targ}) strategy.

15.3.2.5 An evolving base case model

While SERAG accepted the model structure of the preliminary base case assessment for school whiting presented in September 2017, investigations since the September 2017 SERAG discovered that the model had not been properly tuned to ages. The minimum sample size for ages was not sufficiently small to allow appropriate re-weighting of the age-at-length data. As a consequence, the age-at-length variance adjustment parameters were not fully balanced, as instead of some sample sizes being down-weighted below one, they were reset to the minimum sample size (one) at each step and hence were not completely balanced. This particular aspect was not identified until 2 November 2017. This problem has now been corrected (which is only possible with SSv3.30) and fully balanced base case assessment results are presented. There were also issues under SSv3.30 with projections using the Australian Harvest Control rules when the spawning month was set to July. This required a software update (Rick Methot, pers. comm.) and a new version of Stock Synthesis addressing this bug in the code which was not available until 7 November 2017. These problems meant that a full assessment report was unable to be prepared in time for the November 2017 SERAG meeting. However, a provisional base case was able to be presented at this meeting, with the balancing issues addressed, the projections behaving appropriately and with the spawning month set to July and settlement 6 months later.

This arrangement led to a growth curve which was flat between ages 0 and 1, due to the difficulty of resolving the age of fish that were six months old to an integral number of years on the Stock Synthesis census day of January 1. These six month old fish had to be assigned either to age zero or age 1. Assigning them to age zero made little sense and, assigning them to age 1 essentially meant that growth began for fish at age 1 rather than age zero, resulting in an unconventional looking growth curve (Figure 15.7).

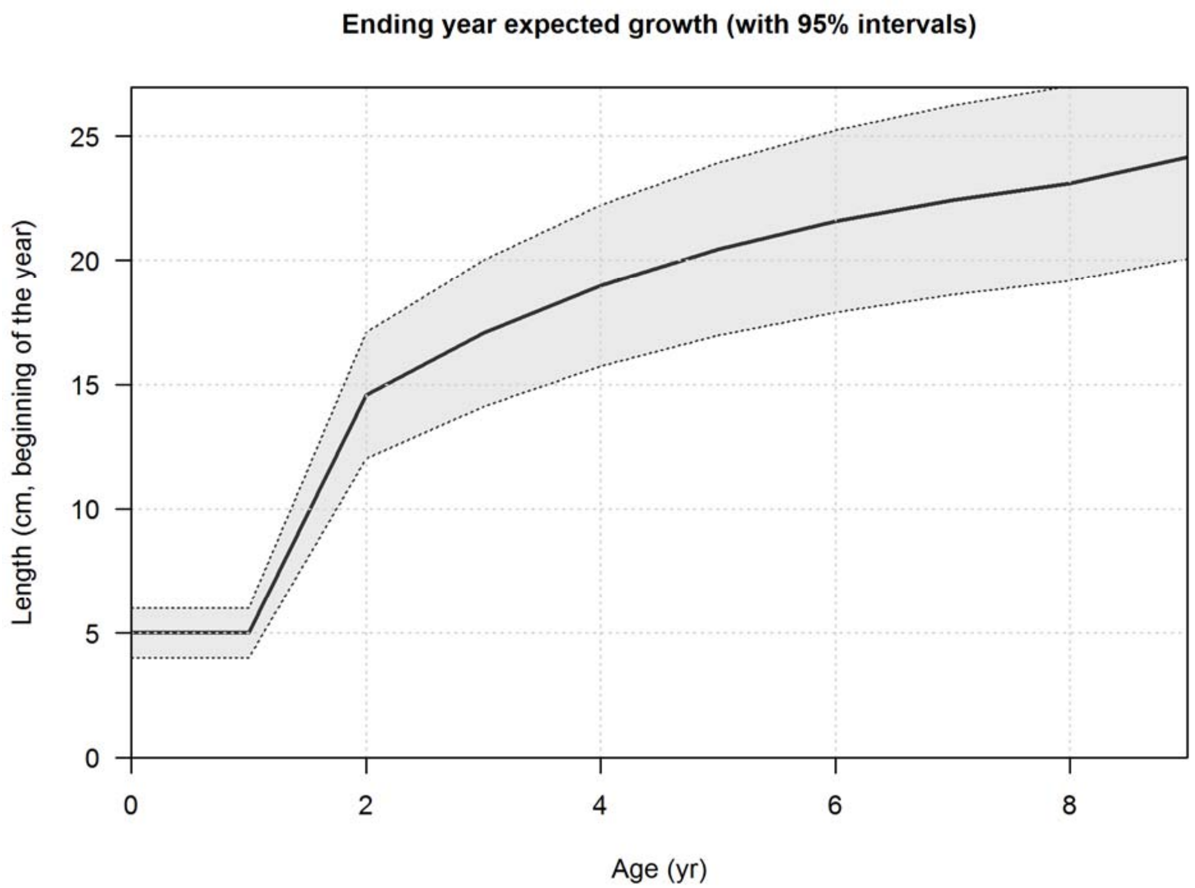

Figure 15.7. Estimated growth curve for the November provisional base case with spawning in July.

At the November SERAG meeting, a decision was made to modify the provisional base case and set the spawning month to January as the base case and consider winter spawning (in July - the November provisional base case) as a sensitivity. This enables the spawning month and the Stock Synthesis census date to line up and produces more conventional and biologically plausible growth curves with growth starting at age zero (Figure 15.8).

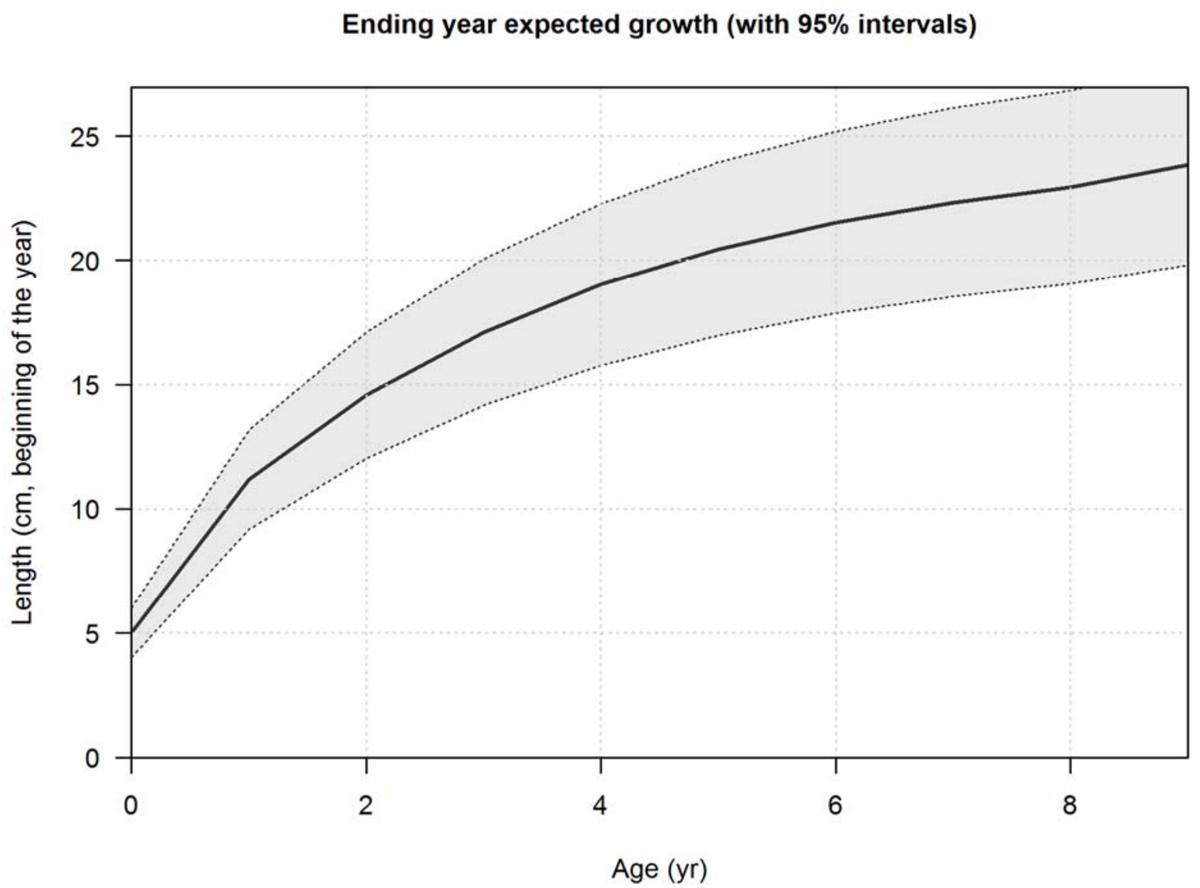

Figure 15.8. Estimated growth curve for the SERAG suggested base case with spawning in January.

While SERAG did not request further changes to the estimated growth curve, investigations of these spawning month issues led to improvements in estimating the growth curve, by estimating growth over a broader range than the length data was available and at a finer resolution. This results in an even smoother growth curve which appears to be a further improvement from a biological perspective (Figure 15.9). This improved fit to growth is included as a sensitivity to the base case agreed at the November SERAG meeting.

Diagnostic figures for the fully balanced base-case model, balanced according to the now agreed tuning methods, and results of sensitivities are provided below. Plots of the time-series of the spawning biomass and recruitment residuals for the agreed base case are similar to those shown at the November SERAG meeting.

Three models are fully balanced in this assessment report to allow SERAG to choose the base case to be used for management advice:

1. July spawning (provisional base case presented at November SERAG.
2. January spawning (November SERAG suggested base case).
3. January spawning with improved growth estimates.

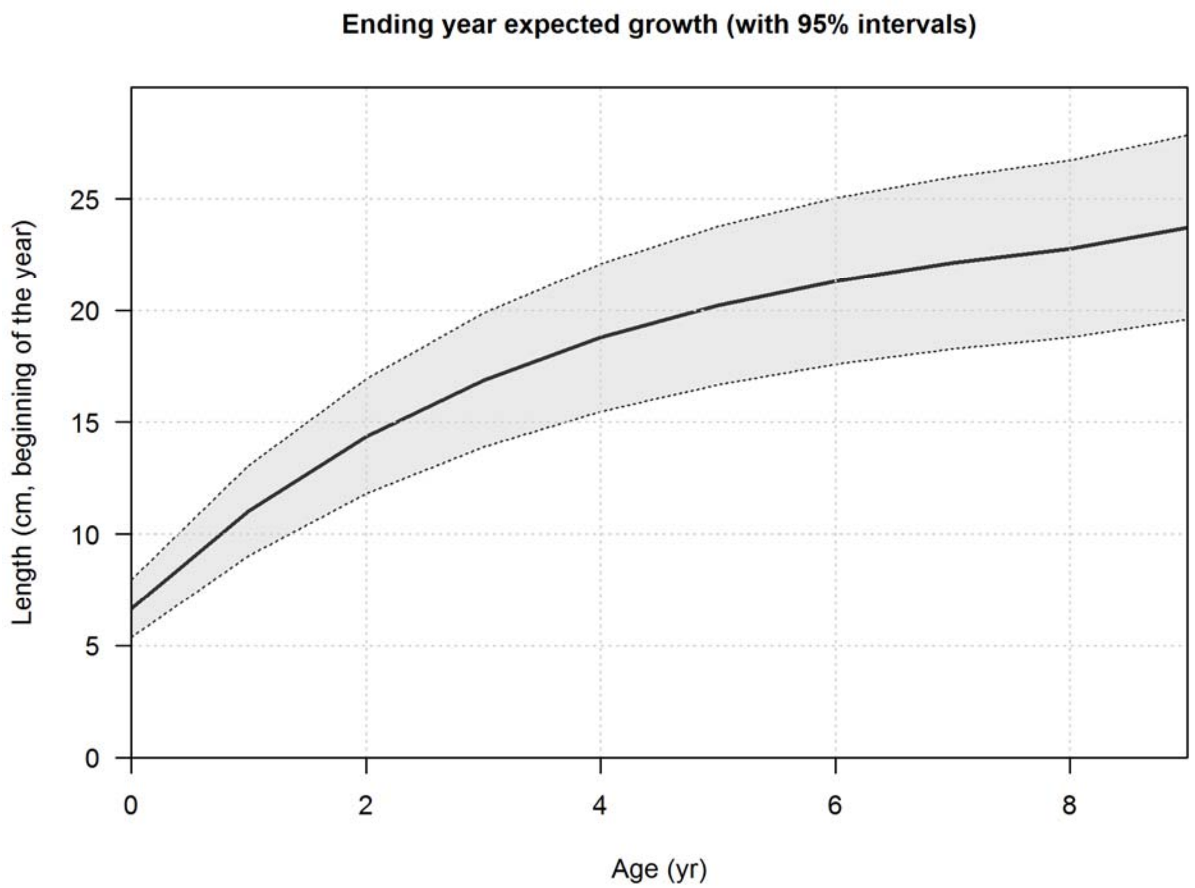

Figure 15.9. Estimated growth curve with improved growth estimates and spawning in January.

15.3.2.6 Sensitivity tests and alternative models

A number of tests were used to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. $h = 0.65$ yr^{-1}.
2. $h = 0.85$ yr^{-1}.
3. 50% maturity at 14 cm.
4. 50% maturity at 18 cm.
5. σ_R set to 0.325.
6. σ_R set to 0.4.
7. Double the weighting on the length composition data.
8. Halve the weighting on the length composition data.
9. Double the weighting on the age-at-length data.
10. Reduce the weighting on the age-at-length data.
11. Increase the weighting on the survey (CPUE) data.

12. Halve the weighting on the survey (CPUE) data.
13. Double the discard values input to the model.
14. Halve the discard values input to the model.
15. Exclude catches north of Barrrenjoey Point.
16. Spawning in July.
17. Improve growth estimates.

The results of the sensitivity tests are summarized by the following quantities (Table 15.12):

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2018}: the female spawning biomass at the start of 2018.
3. SSB_{2018}/SSB_0: the female spawning biomass depletion level at the start of 2018.
4. Mortality: the model estimated value for mortality.
5. RBC_{2018}: the recommended biological catch (RBC) for 2018.
6. $RBC_{2018\text{-}20}$: the mean RBC over the three years from 2018-2020.
7. $RBC_{2018\text{-}22}$: the mean RBC over the five years from 2018-2022.
8. $RBC_{longterm}$: the longterm RBC.

The RBC values were calculated for the final agreed base case only (listed as Sensitivity 17 in this report).

15.4 Results and Discussion

15.4.1 *The base-case analysis*

15.4.1.1 Transition from 2009 base case to 2017 base case

Development of a preliminary base case and a bridging analysis from the 2009 assessment (Day, 2009), was presented at the September 2017 SERAG meeting (Day 2017), including updating the version of Stock Synthesis and sequentially updating data. This bridging analysis is not repeated in this report.

15.4.1.2 Parameter estimates

Figure 15.8 shows the estimated growth curve for school whiting. All growth parameters are estimated by the model (parameter values are listed in Table 15.9).

Table 15.9. Summary of parameters of the base case model.

Feature	**Details**	
Natural mortality *M*	estimated	0.62
Steepness *h*	fixed	0.75
σ_R in	fixed	0.35
Recruitment devs	estimated	1981-2013, bias adjustment ramps 1955-1999 and 2013
CV growth	estimated	0.0821
Growth *K*	estimated	0.287
Growth l_{min}	estimated	9.08
Growth l_{max}	estimated	24.8

Selectivity is assumed to be logistic for all fleets. The parameters that define the selectivity function are the length at 50% selection and the spread (the difference between length at 50% and length at 95% selection). The estimates of these parameters for the Victorian Danish seine fleet are 16.7cm and 2.54cm, for otter trawl are 17.6cm and 2.99cm (somewhat smaller than the selectivity estimated in the 2009 assessment) and for NSW Danish seine are 14.6cm and 2.28cm. The selectivity for the otter trawl fleet is a little smaller (around 2cm) than that estimated in the 2009 assessment, but the selectivity for the other two fleets are similar to that estimated in 2009. Figure 15.10 shows the selectivity and retention functions for each of the commercial fleets. Note that these fitted selectivities show that otter the trawl fleet catches slightly larger fish than either of the Victorian Danish seine fleets and that the NSW Danish seine fleet catches smaller fish than the other two fleets. Retention for the NSW Danish seine fleet was implicitly assumed to be independent of length as no length frequency composition data is available on discards for this fleet. The estimate of the parameter that defines the initial numbers (and biomass), $ln(R_0)$, is 12.6 for the base case.

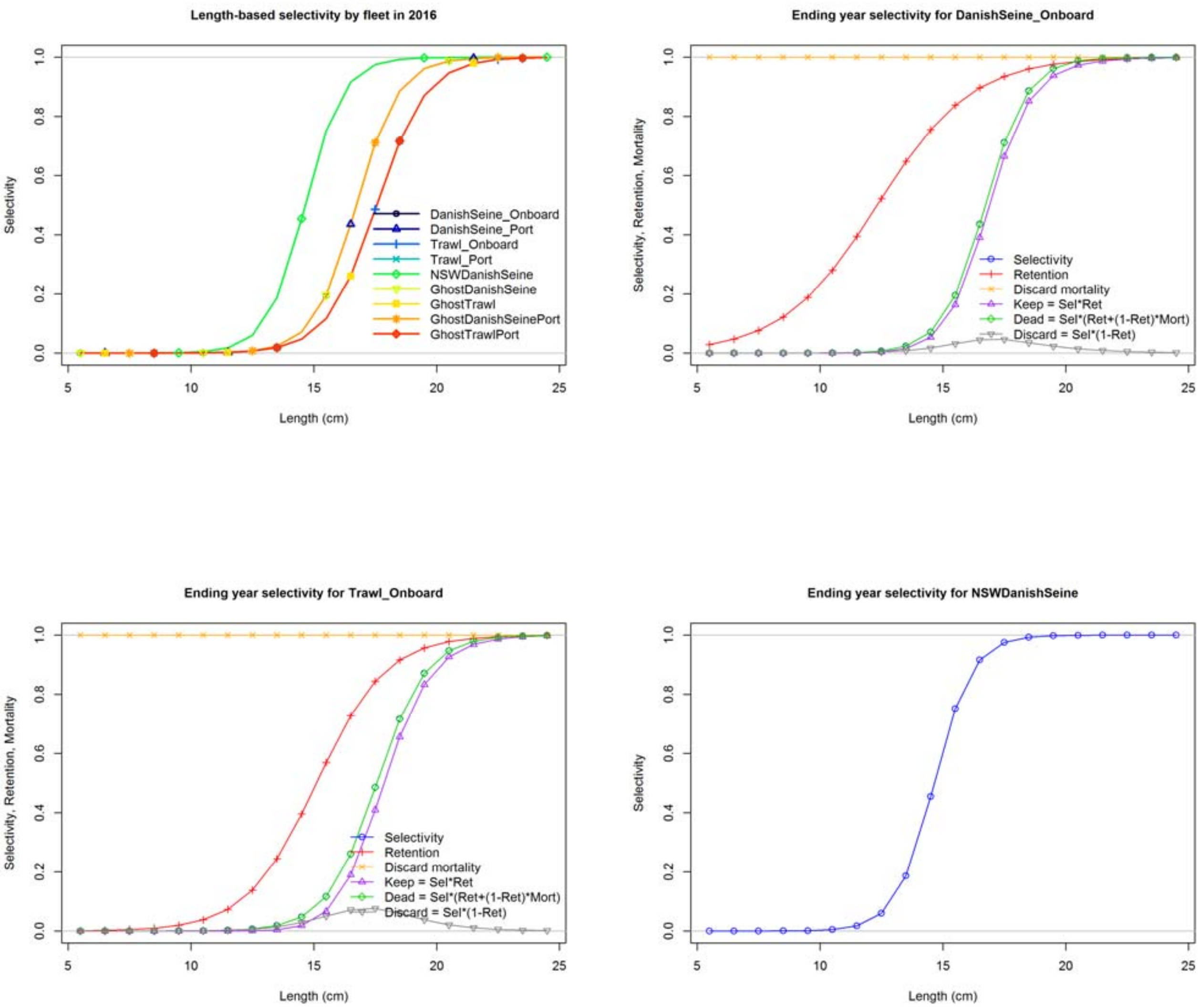

Figure 15.10. Selectivity for all three fleets (top left: Victorian Danish seine (orange); trawl (red); NSW Danish seine (green)) and selectivity (blue/green) and retention (red) functions for the three commercial fleets (Victorian Danish seine (top right); trawl (bottom left); NSW Danish Seine (bottom right)).

15.4.1.3 Fits to the data

The fits to the catch rate indices are remarkably good for the Victorian Danish seine (Figure 15.11) and greatly improved on the fits from the 2009 assessment, especially in relation to matching the timing of the lowest catch rate point in the late 1990s. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model fits well with less variance than the initial values from the loess fit. The fits to the catch rates for the otter trawl fleet (Figure 15.12) are not quite as good, but there is clearly some conflict between the two catch rate series. The additional variance parameter estimated within Stock Synthesis is positive for the otter trawl fleet, suggesting the model requires more variance than the initial values from the loess fit to achieve a good fit. The catch rate indices for the Victorian Danish seine fleet shows a considerable decline from the late 1980s to the late 1990s, with some recovery after that decline, with both series showing a relatively stable trend since the early 2000s.

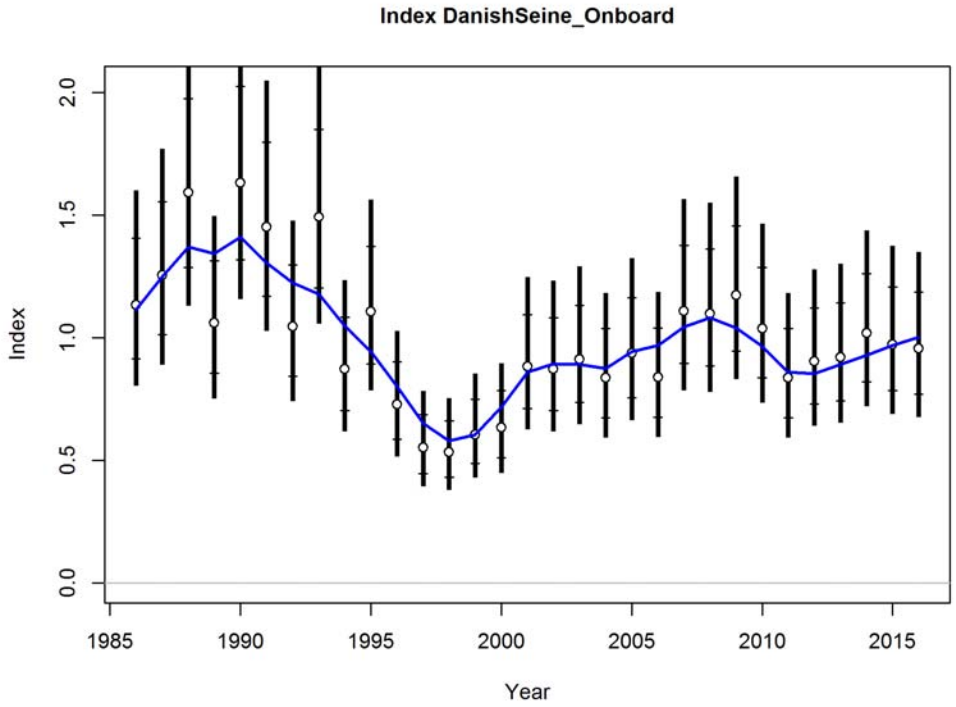

Figure 15.11. Observed (circles) and model-estimated (blue line) catch rates vs year, with approx 95% asymptotic intervals for Victorian Danish seine fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model fits well with less variance than the initial values from the loess fit.

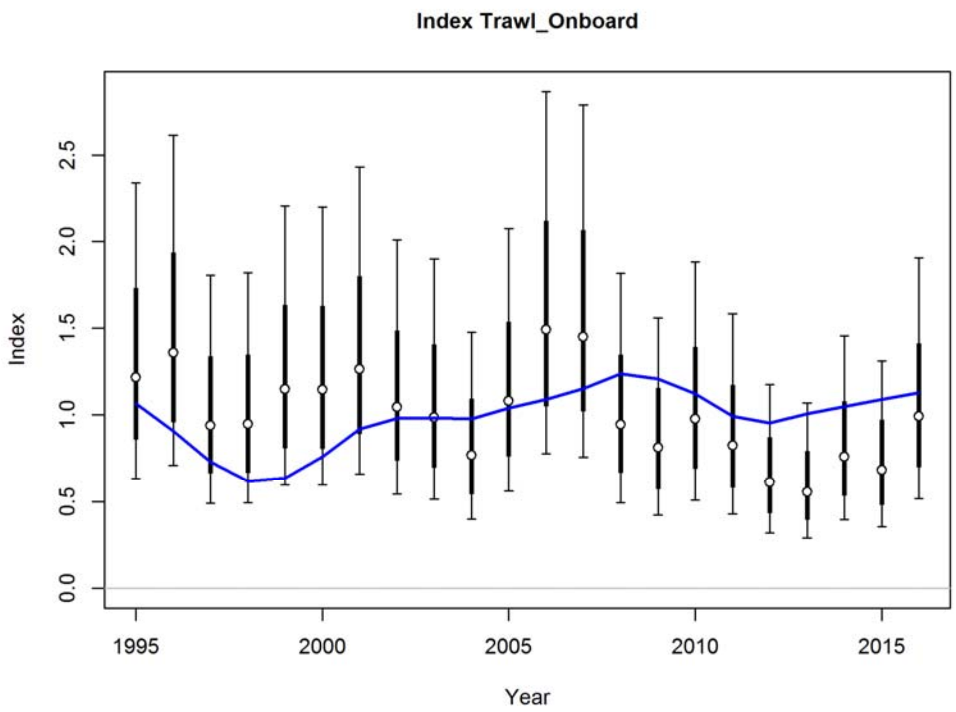

Figure 15.12. Observed (circles) and model-estimated (blue line) catch rates vs year, with approx 95% asymptotic intervals for otter trawl fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is positive, suggesting the model requires more variance than the initial values from the loess fit to achieve a good fit.

The fits to the discard rate data (Figure 15.13) are reasonable for the Victorian Danish seine and acceptable for the otter trawl fleets for the base case. To achieve reasonable levels of predicted discards, six years of very low (<1%) discard rate data were excluded (1995, 2003, 2004, 2010, 2013 for Victorian Danish seine and 2009 for otter trawl, Table 15.3). If these very low discard rates are included in the model, the fitted discard rates match these very low rates well but give very poor fits to all other years with discard rates >1%. Including these low discard rates results in much lower overall predicted discard rates compared to the mean of the discard rates over all years with discard data for each fleet. To achieve predicted discard rates which have a better match to the overall discard rates, these six data points were excluded. In addition to these years with very low discard rates, seven years of discard data for the otter trawl fleet were excluded in 1994, 1995, 2007, 2011, 2013, 2014 and 2016 (with discard rates varying between 4% and 100%) as these data come from sample sizes of less than ten (Table 15.3), resulting in very uncertain estimates of the discard rate for this fleet in these years. Fits to the age and length composition data for discarded catches are shown in Appendix A.

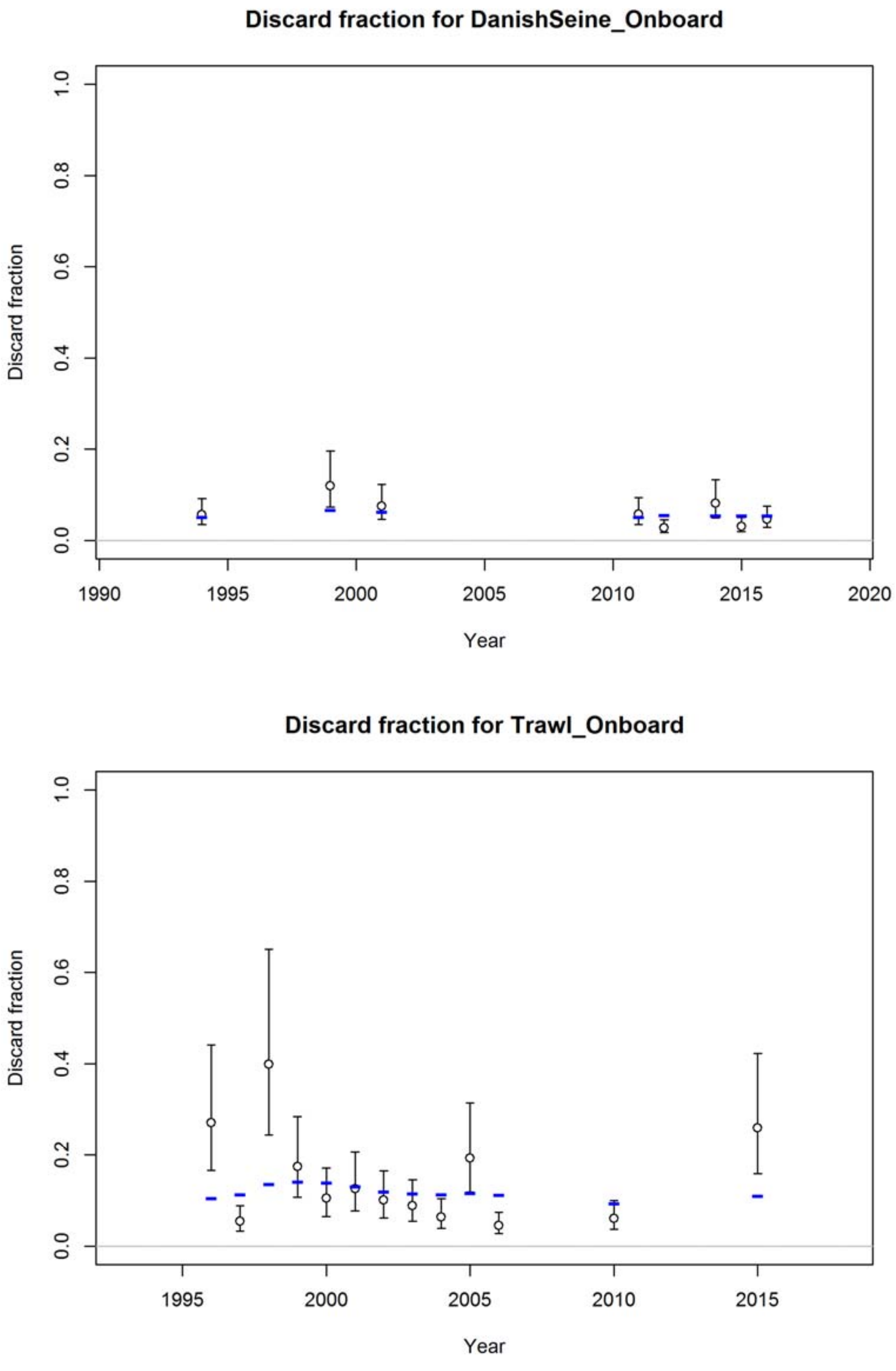

Figure 15.13. Observed (circles) and model-estimated (blue lines) discard estimates versus year for the Victorian Danish seine fleet (top) and the otter trawl fleet (bottom), with approximate 95% asymptotic intervals.

The base-case model is able to fit the retained and discarded length-frequency distributions adequately (Figure 15.14 and Appendix A), with the exception of the discards from the otter trawl fleet. This is not surprising, as the observed discard length frequencies are quite variable from year to year, and actual sample sizes are small in comparison to the retained length frequencies. The aggregated fits to the port measurements are excellent.

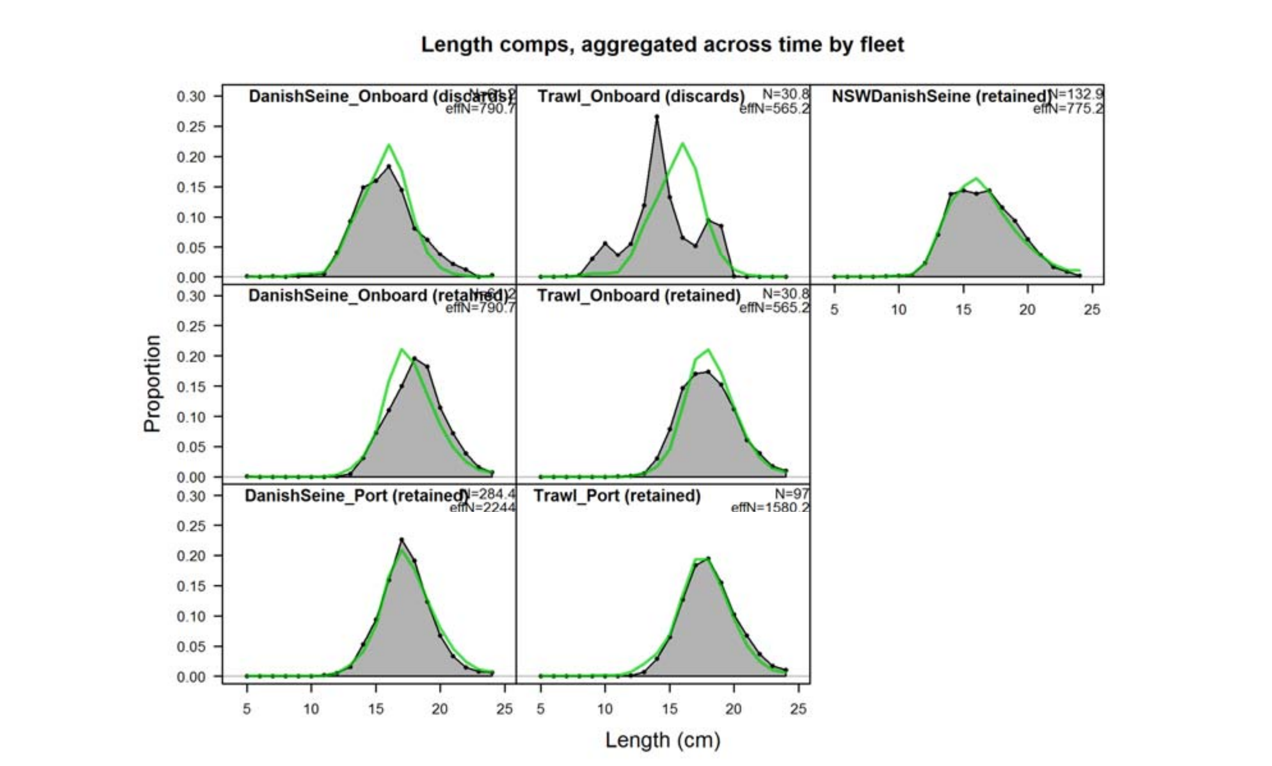

Figure 15.14. Fits to retained and discarded length compositions by fleet, separated by port and onboard samples, aggregated across all years. Observed data are grey and the fitted value is the green line.

The implied fits to the age composition data are shown in Appendix A. The age compositions were not fitted to directly, as age-at-length data were used. However, the model is capable of producing implied fits to these data for years where length frequency data are also available, even though they are not fitted directly in the assessment. The model fits the observed age data reasonably well for the two fleets with age data.

The conditional age-at-length data is quite noisy between years, with occasionally quite large changes in mean age between adjacent years, in some instances larger changes than would be expected through biology and fishing mortality. The mean age varies between 2 and 4 years for Danish seine and between 2 and 3½ years for trawl. This variability in the age-at-length data is likely to be due to spatial or temporal variation in collection of age samples. The fits to conditional age-at-length are as good as can be expected, considering the noise in the data. Residuals for these fits and mean age for each year, aggregated across length bins, are shown in Appendix A.

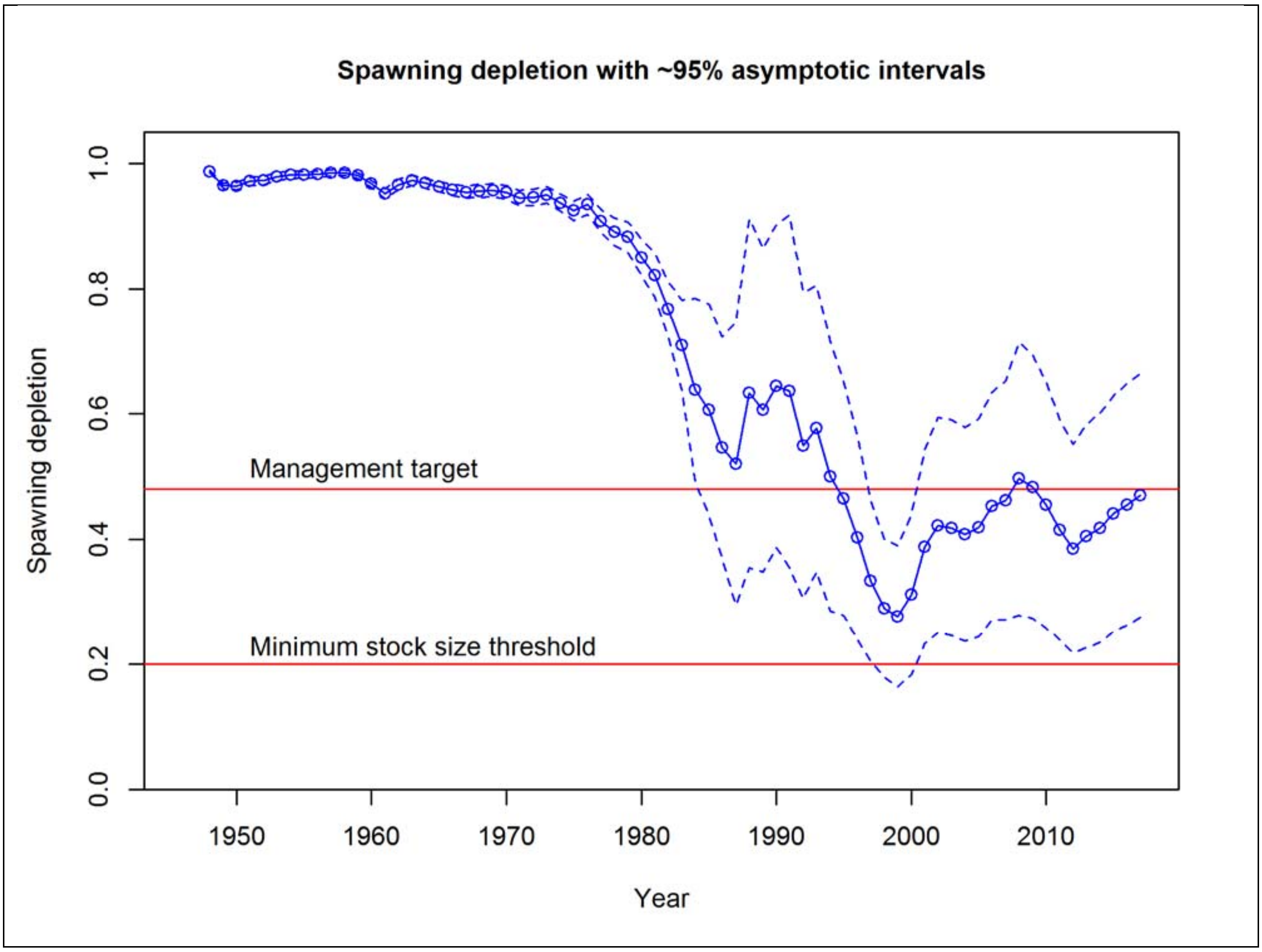

Figure 15.15. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for the base-case analysis for school whiting (January spawning).

15.4.1.4 Assessment outcomes

The current spawning stock biomass (Figure 15.15) is estimated to be 49% of unfished stock biomass (i.e. 2018 spawning biomass relative to unfished spawning biomass), albeit with considerable uncertainty (with 95% asymptotic intervals from around 30% to 70%). The stock declines slowly from the beginning of the fishery in 1947, before a sharp decline in the 1980s corresponding to an increase in catch. The stock declines to 28% SSB_0 in 1999, before increasing to over 40% SSB_0 since 2002 and varying between around 40% and 50% SSB_0 since then. This increase came part way through a period of general decline in total catches over about 20 years, which started in the early 1990s, with this rebound also boosted by good recruitment in 1999, 2003 and 2005 (Figure 15.16). The stock has seen a gradual increase in *SSB* since 2011.

The recoveries in the late 1980s and in the early 2000s are driven by higher recruitment events, especially in the mid 1980s. After these good recruitment events, the stock declined following poor recruitments and continued harvesting (e.g. the period of six consecutive years of average or below average recruitment from 1992-1997) and as a result the stock shows considerable short term sensitivity to recruitment. Generally above average recruitment from 1998-2005 allowed a recovery in the stock from a depletion of 28% in 1999 to a depletion of over 48% in 2007. While the most recent years of recruitment are generally informed by less data and hence could potentially change with the inclusion of additional data in a future assessment, the last four years of estimated recruitment are close to average, so any such changes are unlikely to result in substantial revisions to the spawning biomass.

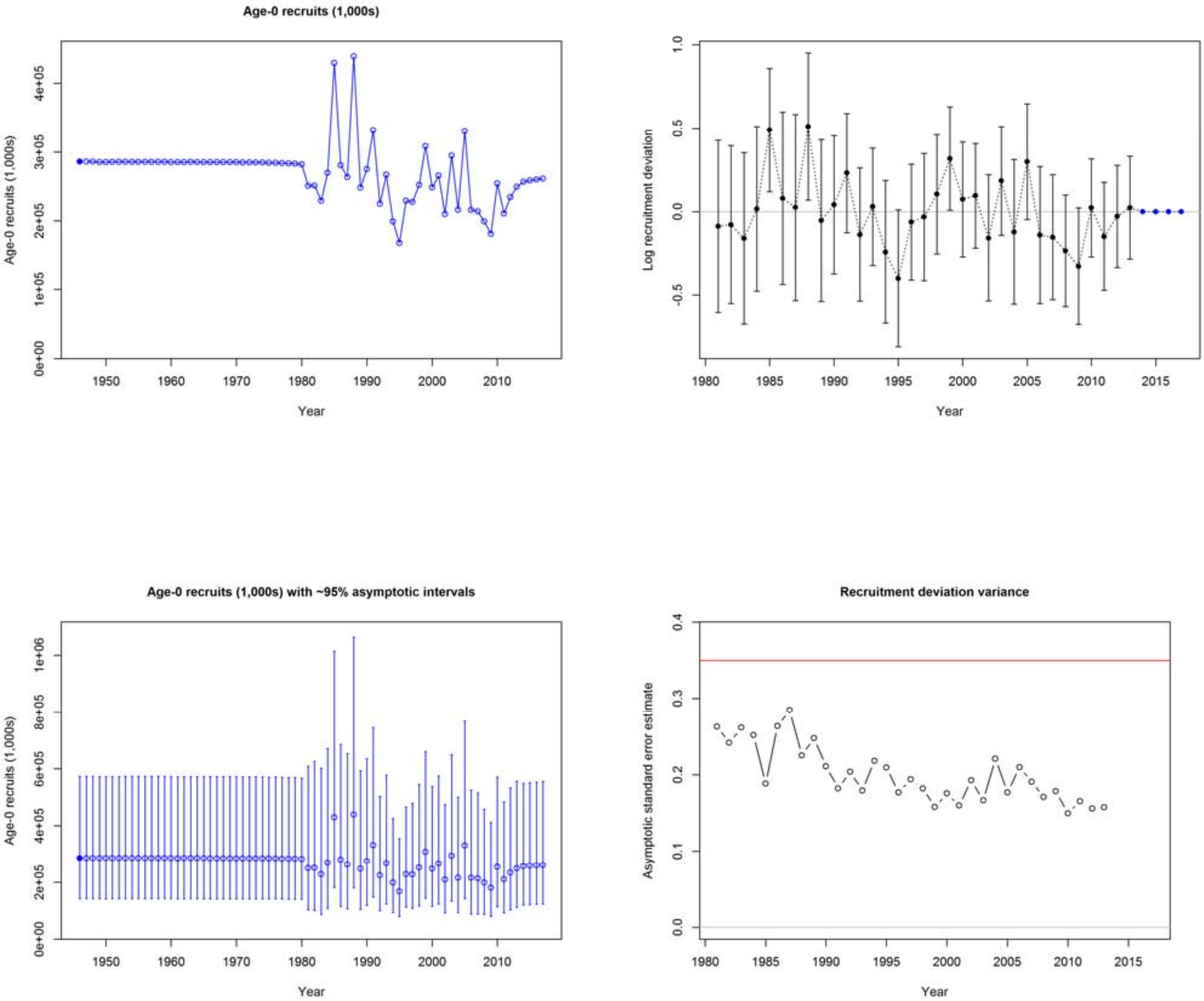

Figure 15.16. Recruitment estimation for the base case analysis. Top left : Time-trajectories of estimated recruitment numbers; top right : time trajectory of estimated recruitment deviations; bottom left : time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; bottom right: the standard errors of recruitment deviation estimates.

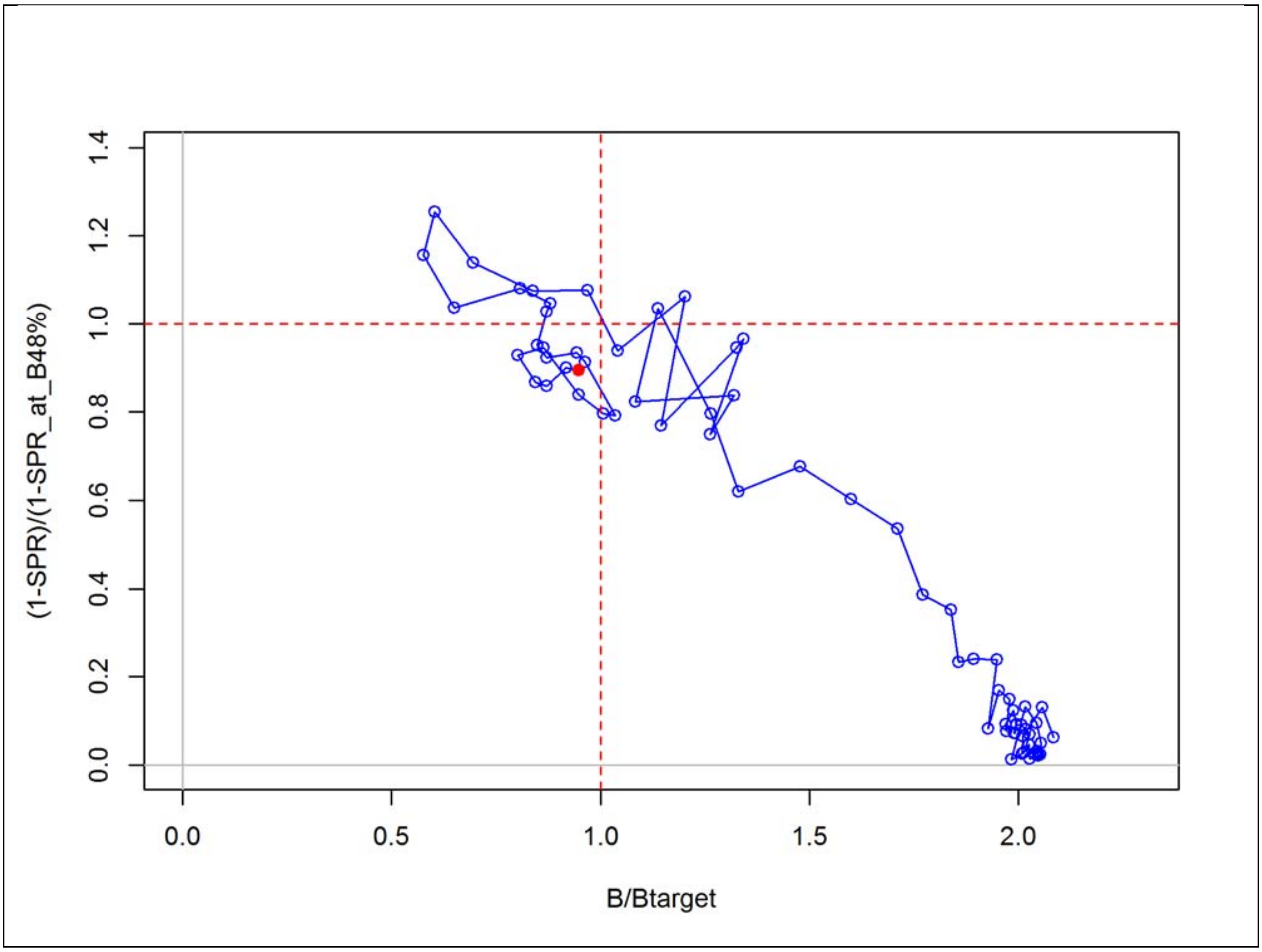

Figure 15.17. Kobe plot base case, showing the trajectory of spawning biomass (relative to B_0) plotted against 1-SPR, which is a proxy for fishing mortality, essentially integrating fishing mortality across fleets in the fishery.

Figure 15.17 shows a Kobe plot for the base case. This plot shows a time series of spawning biomass plotted against spawning potential ratio, which provides a measure of overall fishing mortality, and shows the stepwise movement in this space from the start of the fishery, in the bottom right corner, when there was low fishing mortality and high biomass to the 2017 (the red dot) where the biomass is just below the target (to the left of the vertical red dashed line) and the fishing mortality is below the target fishing level (below the horizontal red dashed line). This trajectory shows an increase in overall fishing mortality as the fishery developed from 1947, with movement from the bottom right corner to the top left corner, when the biomass was well below the target and the fishing mortality was above the target rate. The fishing mortality was gradually reduced from the late 1990s and had been below the “overfishing limit” for the last 13 years, with the spawning biomass generally increasing over this same period.

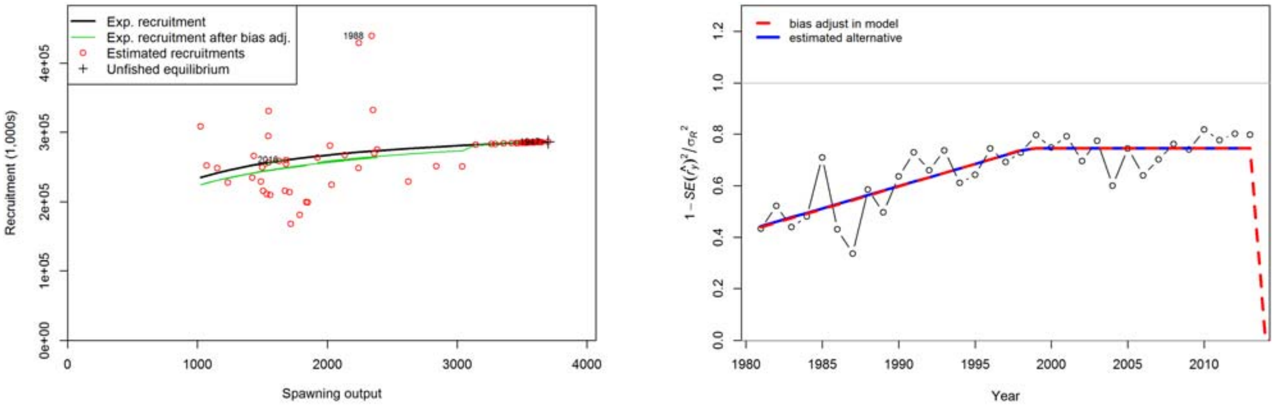

Figure 15.18. Recruitment estimation for the base case analysis. Left: the stock-recruit curve and estimated recruitments; right: bias adjustment.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 15.16. Estimates of recruitments since 1981 are variable with a couple of large recruitment event in the 1980s, two periods of below average recruitment (mid 1990s and late 2000s) with a period of largely above average recruitment in between (from 1998-2005).

The base-case assessment estimates that current spawning stock biomass is 49% of unexploited stock biomass (SSB_0). The 2018 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 1,606 t (Table 15.10) and the long term yield (assuming average recruitment in the future) is 1,641 t (Table 15.12). Averaging the RBC over the three year period 2018-2020, the average RBC is 1,615 t and over the five year period 2018-2022, the average RBC is 1,621 t (Table 15.12). The RBCs for each individual years from 2018-2022 are listed in Table 15.10 for the base case agreed by SERAG in December 2017.

Table 15.10. Yearly projected RBCs (tonnes) across all fleets under the 20:35:48 harvest control rules all assuming average recruitment from 2014 for the agreed base case with January spawning and improved fits to growth (sensitivity 17).

RBCs Year	Jan growth
2018	1,606
2019	1,615
2020	1,623
2021	1,630
2022	1,634

15.4.1.5 Discard estimates

Model estimates for discards for the period 2018-22 with the 20:35:48 Harvest Control Rule are listed in Table 15.11 for the for the base case agreed by SERAG in December 2017, with a range of 119 to 121 t.

Table 15.11. Yearly projected discards (tonnes) across all fleets under the 20:35:48 harvest control rules with catches set to the calculated RBC for each year from 2018 to 2022 for the agreed base case with January spawning and improved fits to growth (sensitivity 17).

Discards Year	Jan growth
2018	119
2019	120
2020	120
2021	121
2022	121

15.4.2 *Sensitivity tests and alternative models*

Results of the sensitivity tests are shown in Table 15.12. Some sensitivities were not able to be completed (halving the weight on age comps, doubling the weight on CPUE, σ_r =0.3) without the model being able to produce results and, in these cases, intermediate sensitivities were conducted, with movement of the respective parameters in the appropriate direction.

As with the 2009 assessment, results are not very sensitive to results are very sensitive to the assumed values for steepness, h, von Bertalanffy k and σ_r (relative to the base-case), but are quite sensitive to the age at 50% maturity. School whiting become sexually mature at two years of age (Smith and Wayte, 2005), which corresponds to a length of around 16cm. Three year olds are about 18cm long and school whiting reach 14cm at about 1½ years old. One year old fish are around 11-12 cm and are unlikely to be sexually mature. Other reports of length at maturity for school whiting range from 15cm in northern NSW (Kevin Rowling, pers comm. based on an unpublished research by Grey and Barnes) and 17cm in Victoria (Hyndes and Potter, 1997, based on data from Hobday and Wankowski (1986)). The base case value for length at 50% maturity has been left at 16cm.

This assessment is not sensitive to the weighting placed on the length compositions or the CPUE series with the depletion ranging from 47% to 53% in these cases. The assessment is more sensitive to the weightings on the age data, with a depletions around 40% if the weighting on age data is either halved or doubled. This suggested that the age data is well tuned, with the likelihood values also deteriorating in both cases (Table 15.13). Some inconsistencies in the age-at-length data between years, indicate that there could be unrepresentative sampling of the age data (either temporally or spatially) or some other dynamics which are unable to be captured by the model. This is also reflected in the sensitivities altering the weighting on the age data and it indicates that the age data is balanced as well as is possible. The length and age data weightings were set according to standard practice in SESSF stock assessments, using iterative reweighting of this data to match input and output effective sample sizes.

Doubling and halving the discard proportions results in depletion ranging from 47% to 53%, but given these inputs are based on data, there appears to be no evidence based justification for making this alterations.

In addition to the standard sensitivities, (cases 1-14 in Table 15.12), four additional sensitivities were investigated.

The initial sensitivity excluding all catch data north of Barrenjoey Point (S15a) has a different catch series which is shown by fleet (with recent NSW Danish seine catches obscured) in Figure 15.19 and by jurisdiction in Figure 15.20. This results in an estimated depletion below 20%. This model is fully balanced. However, further investigation shows that this should not be considered as a serious sensitivity due to the resulting low estimate of mortality (Table 15.12). With less catch data used in this sensitivity, it appears there may not be enough data to adequately estimate mortality. A variation of this sensitivity, using the same modified catch series excluding all catch north of Barrenjoey, with mortality fixed at 0.6 was also conducted (S15). This produced an estimate of 2018 spawning biomass of 39% (Figure 15.21).

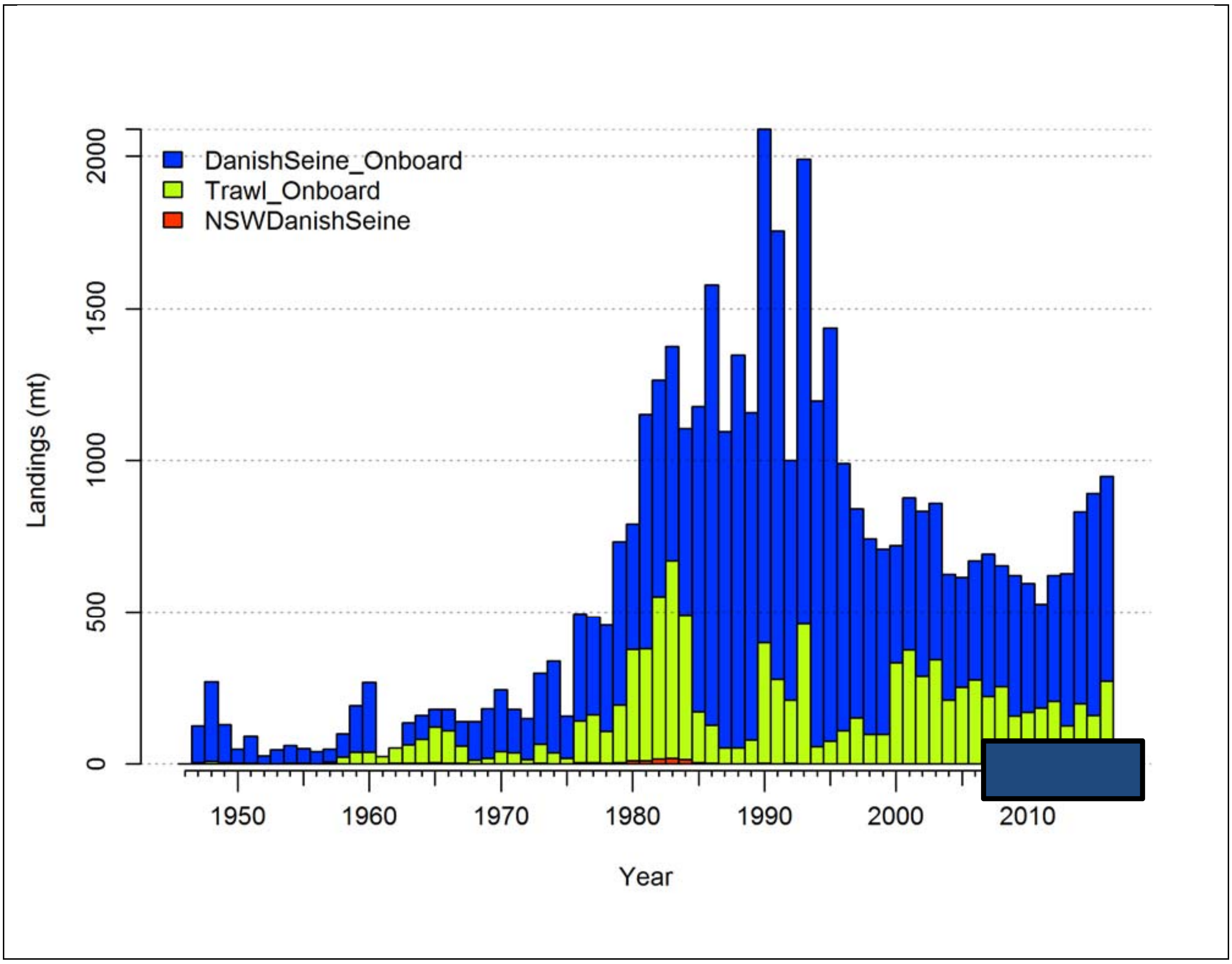

Figure 15.19. Total landed catch (tonnes) of school whiting by fleet (stacked) from 1947-2016 excluding all catches north of Barrenjoey Point. Recent NSW Danish seine catches are not publicly available.

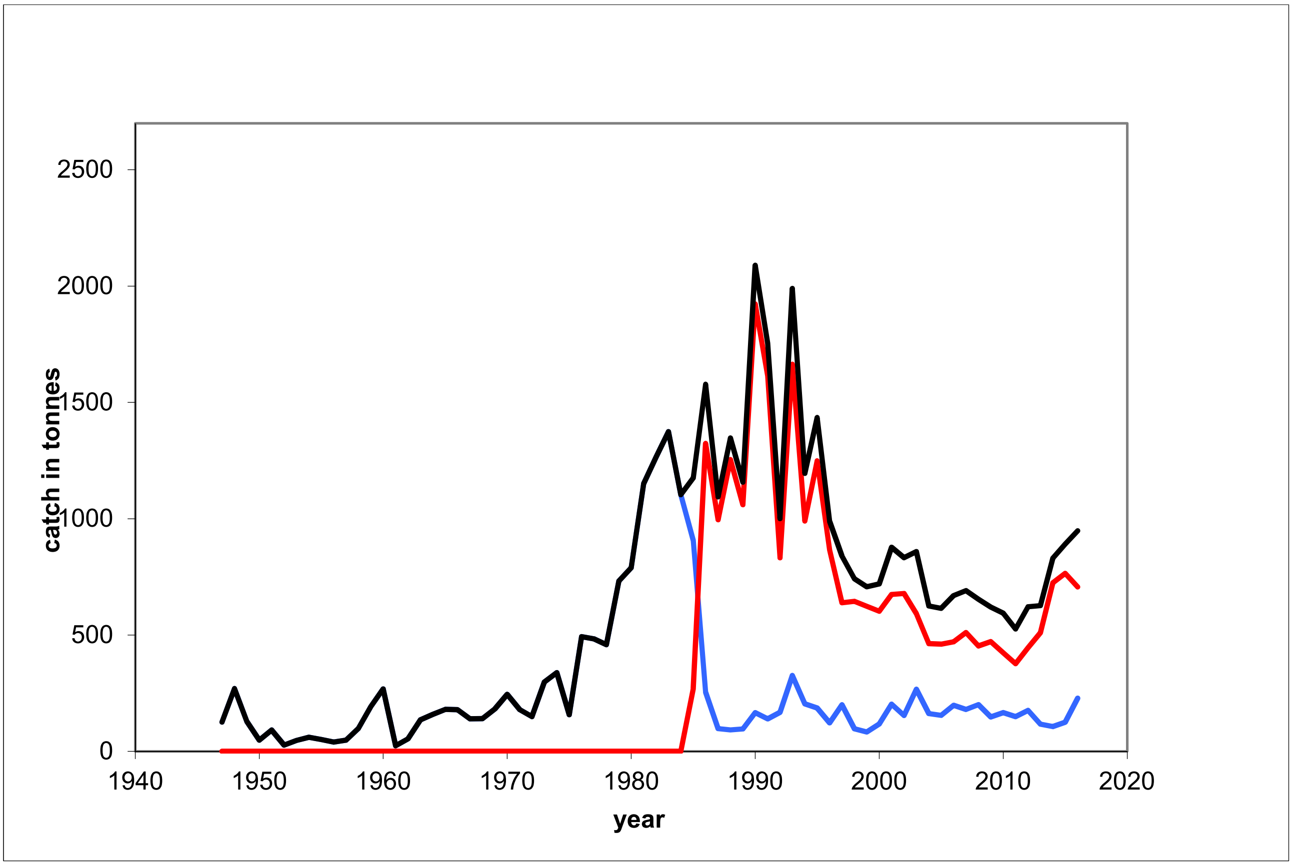

Figure 15.20. Total landed catch of school whiting in the SESSF from 1947-2016 (black line with circles) excluding all catches north of Barrenjoey Point, and this same catch separated into jurisdiction with state catches (blue) and Commonwealth catches (red). The Commonwealth catch south of Barrenjoey Point is considerably larger than the state catch south of Barrenjoey Point from 1987-2016. The state catches (blue) comprise the whole catch until 1985. The Commonwealth catch starts in 1985.

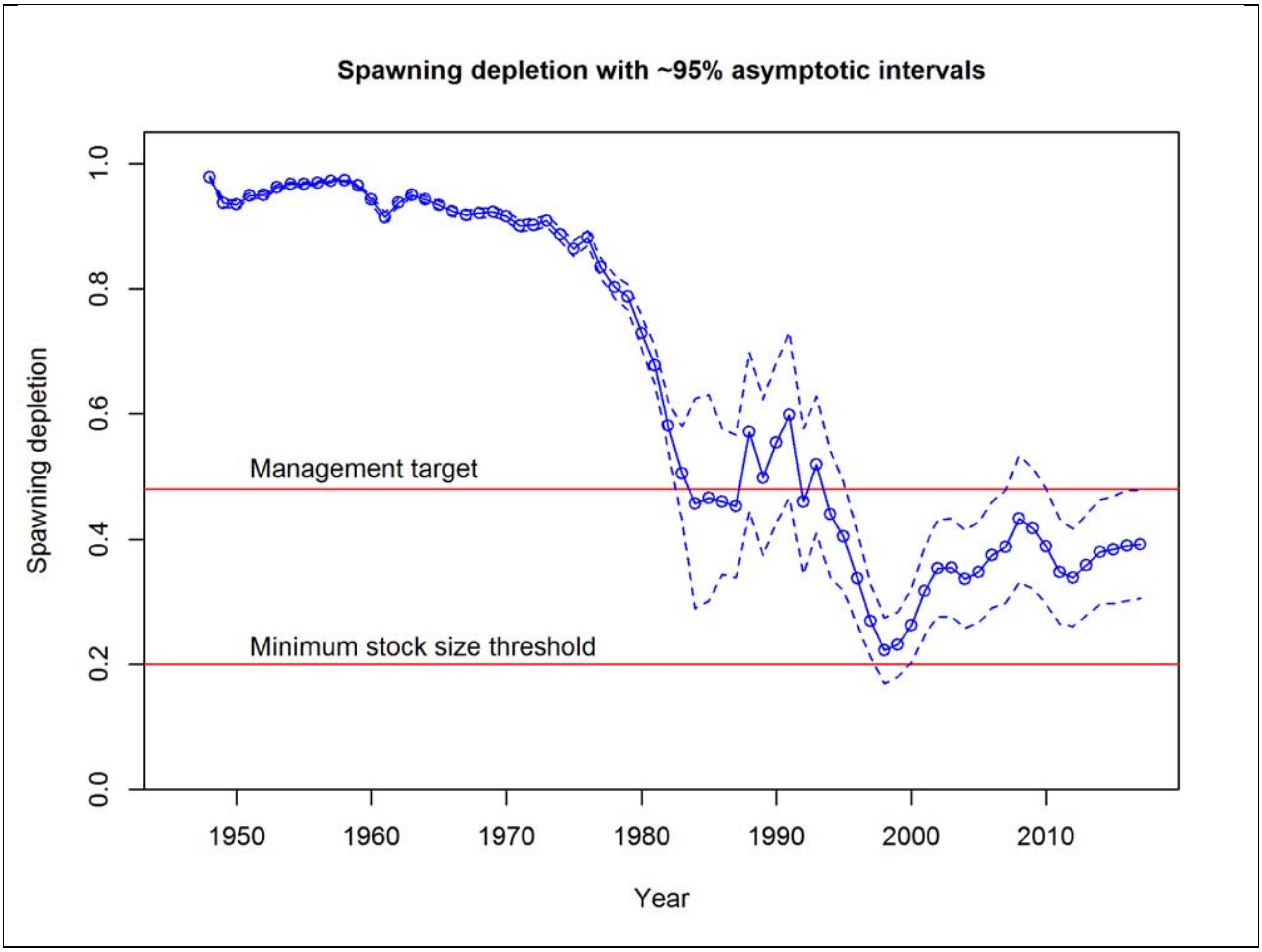

Figure 15.21. Time-trajectory of spawning biomass depletion for school whiting (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for Sensitivity 15, excluding all catches north of Barrenjoey Point.

The sensitivity with winter spawning (S16) produced very similar results to the base case with January spawning (Table 15.12). Improving the fit to the growth (S17) also produced very similar results (Table 15.12). Comparative plots are shown for relative spawning biomass (Figure 15.21) and recruitment series (Figure 15.22) for: the November provisional base case with July spawning (blue); the SERAG suggested base case with January spawning (red); and the model with improved growth estimates and January spawning (green), illustrating the similarities in the results from these three alternative base cases.

Unweighted likelihood components for the base case and differences for the sensitivities reveal several points (Table 15.13). The overall likelihood is only improved for the sensitivity excluding data north of Barrenjoey (S15), but in this case comparison of likelihood is not meaningful due to the difference in data inputs between this sensitivity and the base case. Apart from this one case, none of the sensitivities show an improvement in overall likelihood, indicating that the model is not greatly sensitive to the variations in parameters tested, that the model is remarkably stable and well balanced.

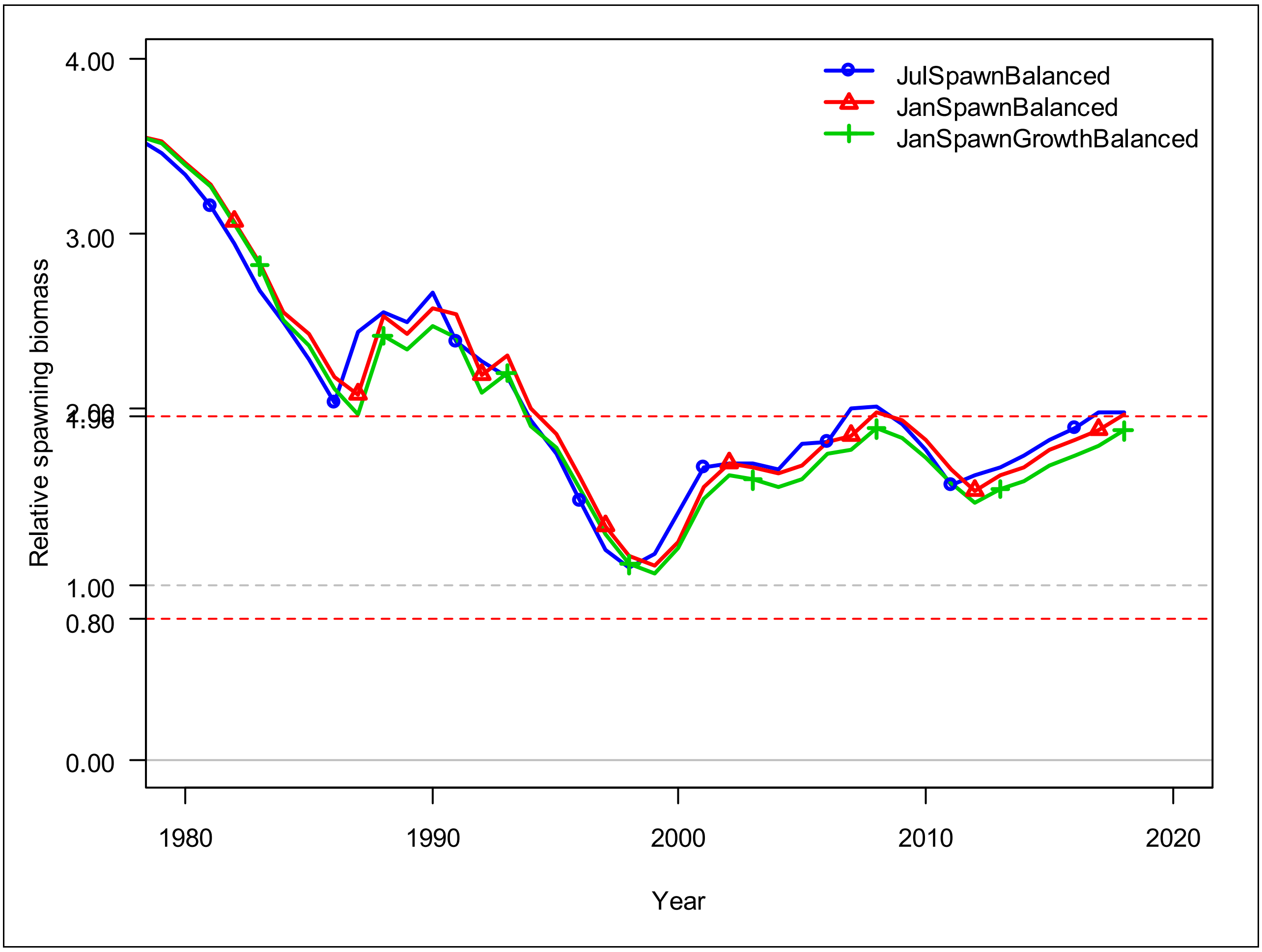

Figure 15.22. Comparative spawning biomass time series for: the November provisional base case with July spawning (blue); the SERAG suggested base case with January spawning (red); and the model with improved growth estimates and January spawning (green). Note the translation of the series to the right for January spawning.

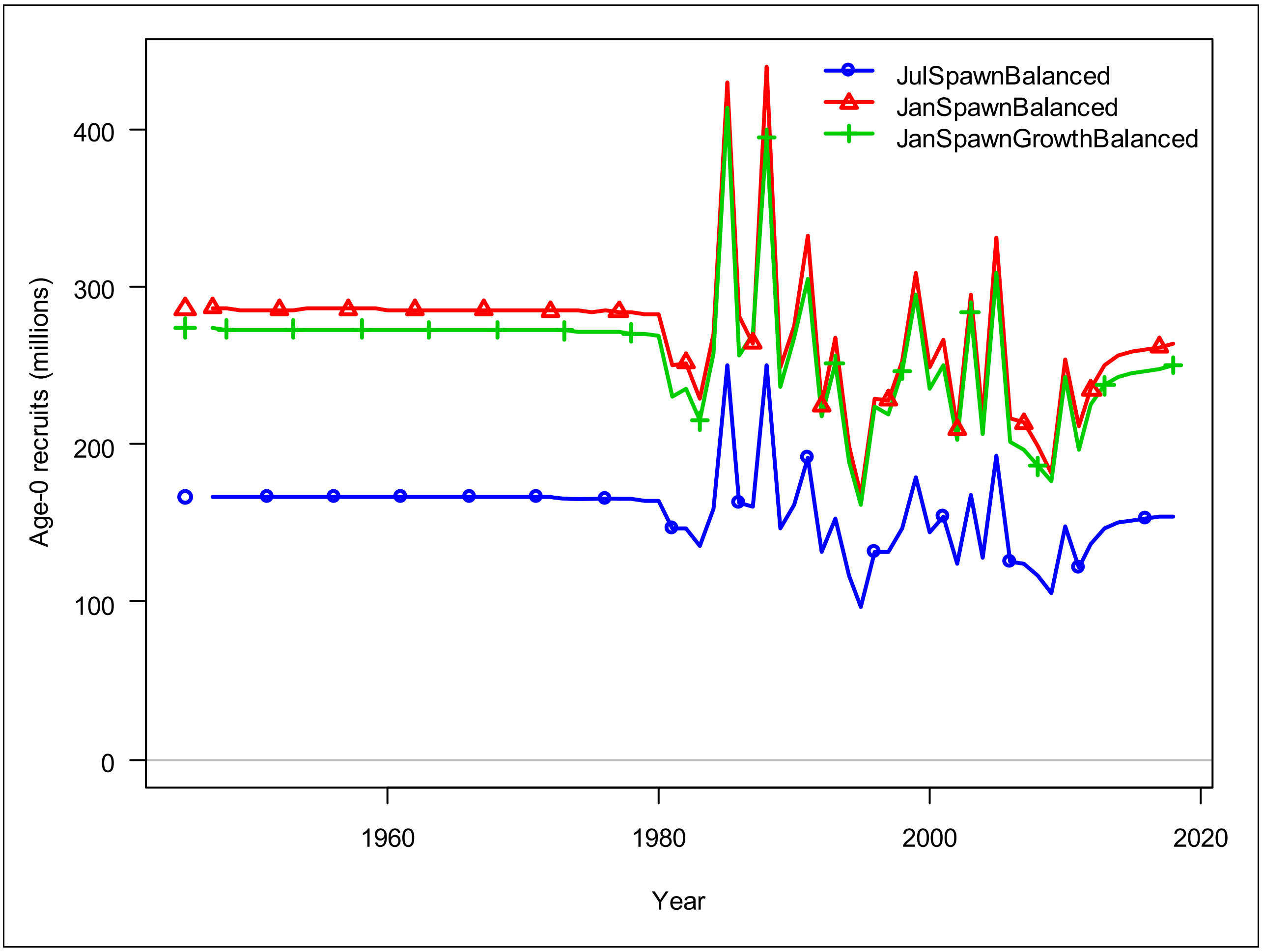

Figure 15.23. Comparative recruitment series for: the November provisional base case with July spawning (blue); the SERAG suggested base case with January spawning (red); and the model with improved growth estimates and January spawning (green). Note the change in absolute value of recruitment when the spawning month is changed. This relates to mortality up to age one being applied to either six months (July spawning) or 12 months (January spawning).

15.4.3 *Future work*

15.4.3.1 Stock structure

Further genetic work to determine any stock structure would be very useful. If such work was to produce clear suggestions recommending geographical separation of stocks, issues relating to separation of the data input to the assessment to match any new stock structure would need to be addressed.

15.4.3.2 2010 age data

The 2010 Danish seine age-at-length data needs to be properly coded so this data can be included in a future assessment. This should be a straightforward addition to the next stock assessment.

15.4.3.3 NSW state data

Provision of NSW state data for a future stock assessment, including discarding rates, length and age composition data and possible catch rate data would be very useful, especially as this would provide more information on the fishery at the northern part the distribution. The current model has limited information on this part of the fishery.

15.4.3.4 Likelihood profiles

A likelihood profile on R_0 would be a useful diagnostic to provide in a future assessment.

15.4.3.5 Retrospective analyses

Retrospective analyses could also be useful diagnostics, although there is no indication of any pathological behaviour with recent estimates of recruitment deviations being close the average.

Table 15.12. Summary of results for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for agreed base case model models (Case 17).

Case		SSB_0	SSB_{2018}	SSB_{2018}/SSB_0	Mortality	RBC_{2018}	$RBC_{2018\text{-}20}$	$RBC_{2018\text{-}22}$	$RBC_{longterm}$
0	base case Jan spawn	7,399	3,568	0.48	0.62				
1	h 0.65	7,769	3,758	0.48	0.65				
2	h 0.85	7,131	3,586	0.50	0.60				
3	50% maturity at 14cm	9,086	5,191	0.57	0.61				
4	50% maturity at 18cm	5,415	2,188	0.40	0.65				
5	$\sigma_R = 0.325$	7,379	3,590	0.49	0.61				
6	$\sigma_R = 0.4$	7,451	3,764	0.51	0.63				
7	wt x 2 length comp	7,589	3,667	0.48	0.59				
8	wt x 0.5 length comp	7,387	3,596	0.49	0.63				
9	wt x 2 age comp	7,295	2,983	0.41	0.55				
10	wt x 0.75 age comp	6,959	2,693	0.39	0.55				
11	wt x 1.5 CPUE	7,256	3,820	0.53	0.65				
12	wt x 0.5 CPUE	7,530	3,519	0.47	0.59				
13	discard proportion x 2	8,163	4,334	0.53	0.64				
14	discard proportion x 0.5	7,110	3,361	0.47	0.61				
15a	exclude catch north of BJ	5,551	917	0.17	0.43				
15	BJ with M=0.6	4,287	1,691	0.39	0.60				
16	Jul spawn	7,317	3,624	0.50	0.64				
17	improved growth	7,547	3,539	0.47	0.59	1,606	1,615	1,621	1,641

Table 15.13. Summary of likelihood components for the base-case and sensitivity tests. Likelihood components are unweighted, and cases 1-17 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Case		**Likelihood**						
		TOTAL	**Survey**	**Discard**	**Length comp**	**Age comp**	**Recruitment**	**Parm_priors**
0	base case Jan spawn	95.41	-66.18	23.09	91.60	63.40	-17.30	0.58
1	h 0.65	0.14	-0.19	0.24	-0.27	-0.08	0.18	0.30
2	h 0.85	0.10	0.14	-0.16	0.22	0.05	-0.06	-0.11
3	50% maturity at 14cm	0.00	0.12	-0.14	0.14	0.02	-0.16	0.00
4	50% maturity at 18cm	0.18	-0.11	0.35	-0.27	-0.10	0.35	0.00
5	$\sigma_R = 0.325$	-0.75	0.57	0.00	-0.02	0.01	-1.31	0.00
6	$\sigma_R = 0.4$	1.47	-1.07	0.04	0.10	0.02	2.39	0.00
7	wt x 2 length comp	2.21	3.66	2.70	-4.75	0.54	0.05	0.00
8	wt x 0.5 length comp	1.45	-0.53	-3.08	4.91	-0.11	0.28	0.00
9	wt x 2 age comp	7.05	3.87	-0.83	2.51	1.05	0.10	0.01
10	wt x 0.75 age comp	6.20	2.03	-1.93	1.32	4.20	0.15	0.01
11	wt x 1.5 CPUE	1.48	-5.33	1.03	1.74	1.00	3.08	0.01
12	wt x 0.5 CPUE	1.41	5.23	-0.89	-1.25	-0.39	-1.32	0.00
13	discard proportion x 2	2.02	-0.15	2.02	0.53	-0.33	-0.02	0.00
14	discard proportion x 0.5	-1.12	0.38	-1.00	-0.54	0.20	-0.18	0.00
15a	exclude catch north of BJ	-9.71	-8.77	-2.86	-1.95	-3.22	6.97	0.05
15	BJ with M=0.6	-4.08	-4.82	-1.47	-1.55	-2.02	5.88	0.00
16	Jul spawn	-1.37	0.44	0.13	-0.42	-1.62	0.07	0.05
17	improved growth	2.36	1.04	-0.47	1.20	0.35	0.19	0.05

15.5 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus and Robin Thomson (CSIRO) pre-processed the data. Karina Hall (NSW DPI) provided NSW catch data and advice on school whiting fisheries in NSW state waters. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided R code for organising plots. Geoff Tuck, Malcolm Haddon, André Punt, Robin Thomson, Miriana Sporcic, Claudio Castillo-Jordán and Neil Klaer are thanked for helpful discussions on this work. Ian Taylor and Rick Methot from NOAA are thanked for considerable technical advice on Stock Synthesis and r4ss and other contributions to this assessment.

15.6 References

Anonymous 1992. Length Frequency distributions for south east trawl fish species measurements at Lakes Entrance and Portland, 1991-92. Report from Department of Conservation and Natural Resources, Fisheries Branch, October 1992, 20pp.

Bax NJ, and Knuckey IA 2002. Draft. Evaluation of selectivity in the South-East fishery to determine its sustainable yield. Final Report to the Fisheries Research and Development Corporation. FRDC Project 96/140.

Cui G, Punt, AE and Cope JM 2004. Summary of the stock assessment for school whiting (Sillago flindersi) based on data up to 2003. In: Tuck, G.N. and Smith, A.D.M. (Eds.) Stock assessment for southern and eastern scalefish and shark fishery 2004-2005 and southern shark fishery species. Fisheries Research and Development Corporation and CSIRO Marine Research, Hobart 222 pp.

Day J. 2007. School whiting (Sillago flindersi) stock assessment based on data up to 2006. Unpublished report to Shelf RAG. 55 pp.

Day J. 2008a. Modified breakpoint for the 2008 Tier 1 harvest control rule. Unpublished report to Shelf RAG. 6 pp.

Day J. 2008b. School whiting (Sillago flindersi) stock assessment based on data up to 2007. Unpublished report to Shelf RAG. 63 pp.

Day J. 2017. School whiting (Sillago flindersi) stock assessment based on data up to 2016 – development of a preliminary base case. Unpublished report to SERAG. 48 pp.

Dixon PI, Crozier RH and Black M 1986. School whiting – how many species. Australian Fisheries Journal, 45: 33-38.

Dixon PI, Crozier RH Black M and Church A 1987. Stock identification and discrimination of commercially important whitings in Australian waters using genetic criteria. Final Report, Centre for Marine Science, University of New South Wales.

Haddon M and Sporcic M 2017. Statistical CPUE standardizations for selected SESSF species (data to 2016). Document prepared for SE RAG Meeting November 2017. Hobart. 270 pp.

Hobday DK and Wankowski JWJ 1986. Age determination of school whiting. Internal Report No. 130, Victorian Department of Conservation, Forests and Lands, Fisheries Division, Queenscliff. 21 pp.

Hyndes GA and Potter IC 1997. Age, growth and reproduction of Sillago schomburgkii in south-western Australian, nearshore waters and comparisons of life history styles of a suite of Sillago species. Env. Biol. of Fishes 49: 435–447.

Klaer N and Thomson R 2006. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2006.

Methot RD 2005. Technical Description of the Stock Synthesis II Assessment Program Version 1.17 – March 2005. NOAA Fisheries Internal Report.

Methot RD 2009. User manual for Stock Synthesis. Model Version 3.03a. NOAA Fisheries Service, Seattle. 143 pp.

Methot RD, A'mar T, Wetzel C and Taylor I 2017. Stock Synthesis User manual. Version 3.30.05. NOAA Fisheries Service, Seattle. 183 pp.

Pease BC and Grinberg A 1995. New South Wales commercial fisheries statistics 1940 to 1992. Fisheries Research Institute report, 351 pp.

Punt AE 1999. ADAPT and integrated analysis assessments of school whiting. Document submitted to the 17-18 June 1999 school whiting workshop 18pp.

Punt AE Smith DC and Koopman MT 2005. Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods. Final report to Fisheries Research and Development Corporation. FRDC Project 2002/094. Primary Industries Research Victoria, Queenscliff.

Richards LJ, Schnute JT, Kronlund .R and Beamish RJ 1992. Statistical models for the analysis of ageing error. Can. J. Fish. Aquat. Sci. 49: 1801–1815.

Smith ADM, Smith DC, Tuck GN, Klaer N, Punt AE, Knuckey I, Prince J, Morison A, Kloser R, Haddon M, Wayte S, Day J, Fay G, Fuller M, Taylor B and Little LR 2008. Experience in implementing harvest strategies in Australia's south-eastern fisheries. Fish.Res. 94: 373–379.

Smith ADM and Wayte SE (eds) 2005. The Southern and Eastern Scalefish and Shark Fishery 2004, Fishery Assessment Report compiled by the Southern and Eastern Scalefish and Shark Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Wankowski JWJ 1983. The Lakes Entrance Danish seine fishery for tiger flathead, school whiting and jackass morwong, 1947-1978. Technical Report No. 30 from Department of Conservation Forests and Lands, Fisheries Branch, July 1983, 30pp.

15.7 Appendix A

15.7.1 *Fits to length composition, implied fits to age composition, and diagnostics for fits to conditional age-at-length data.*

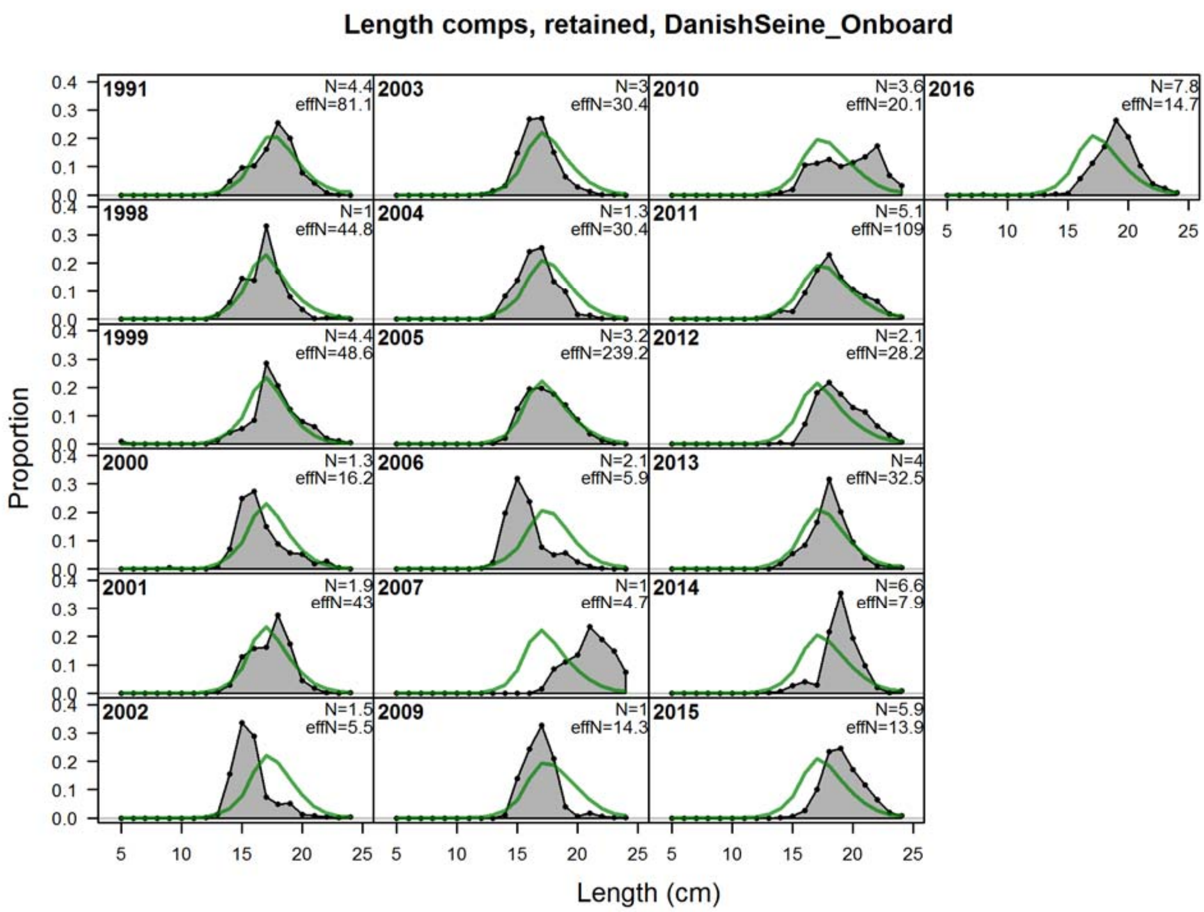

Figure A 15.1. School whiting length composition fits: Danish seine onboard retained..

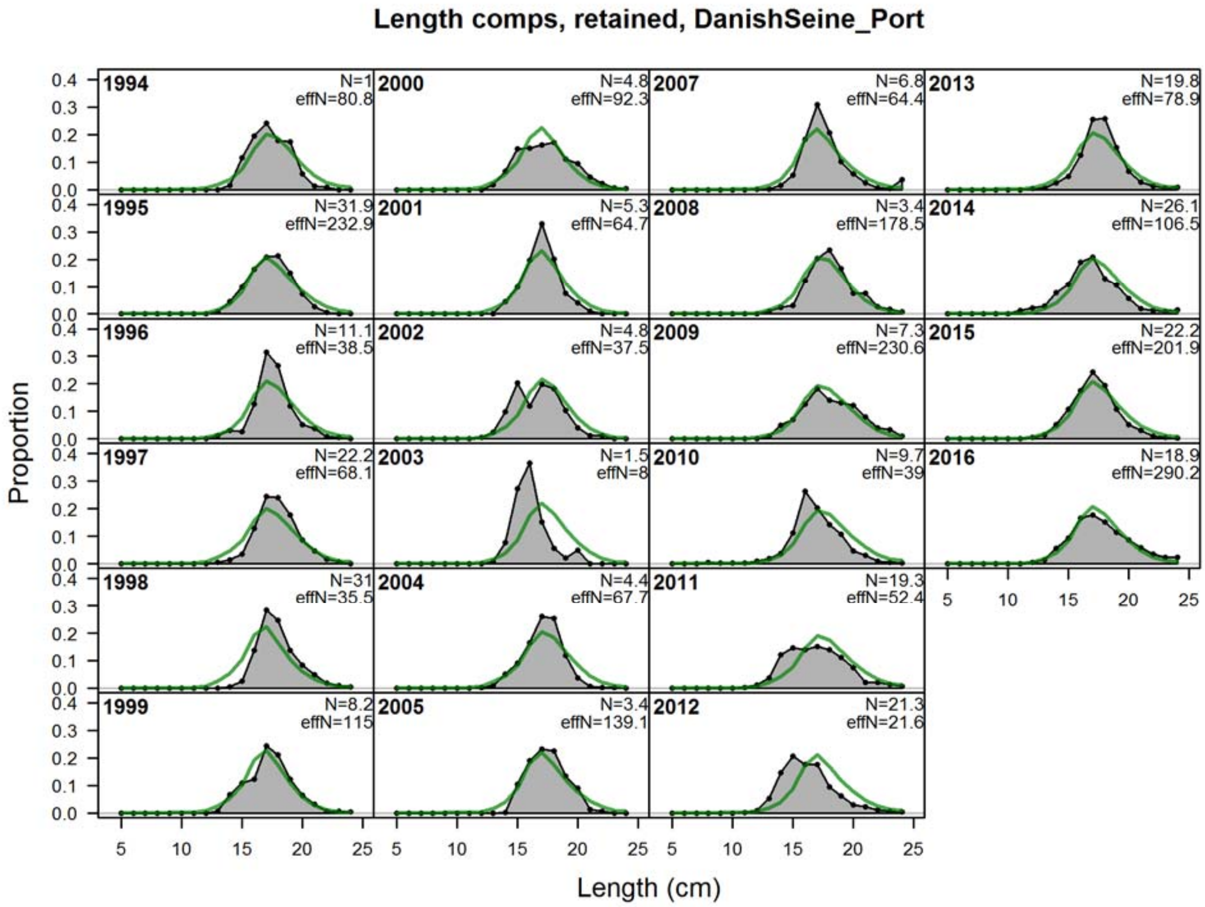

Figure A 15.2. School whiting length composition fits: Danish seine port retained.

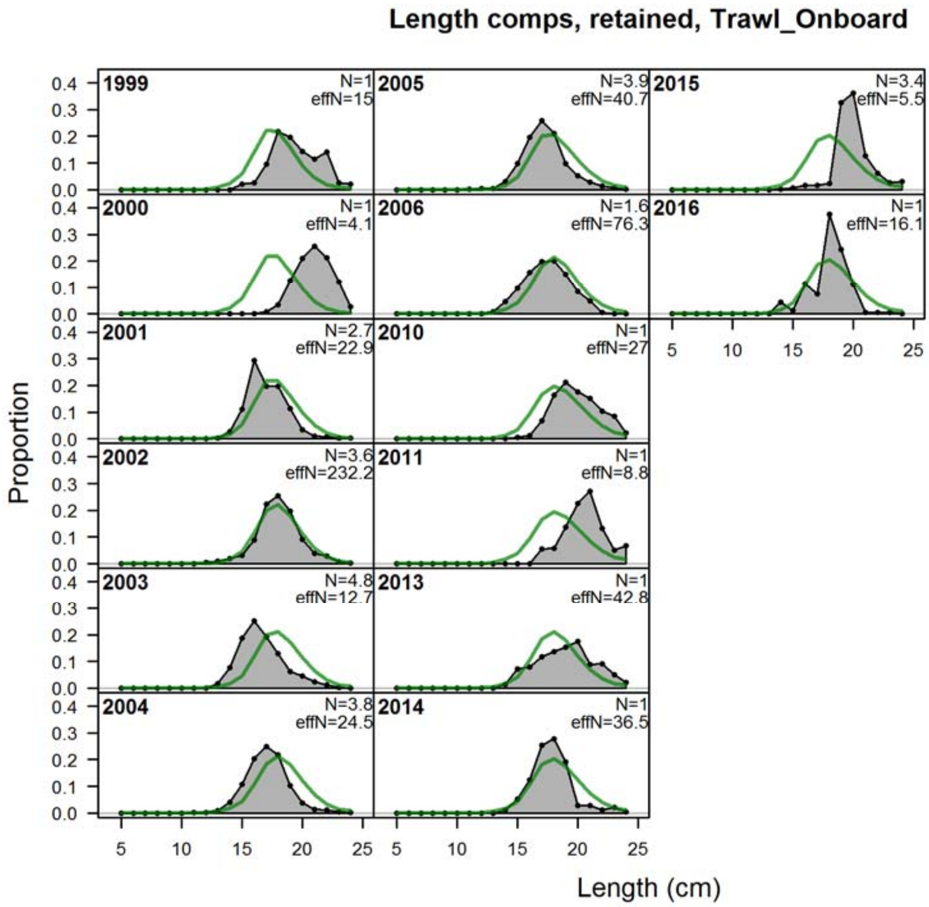

Figure A 15.3. School whiting length composition fits: trawl onboard retained.

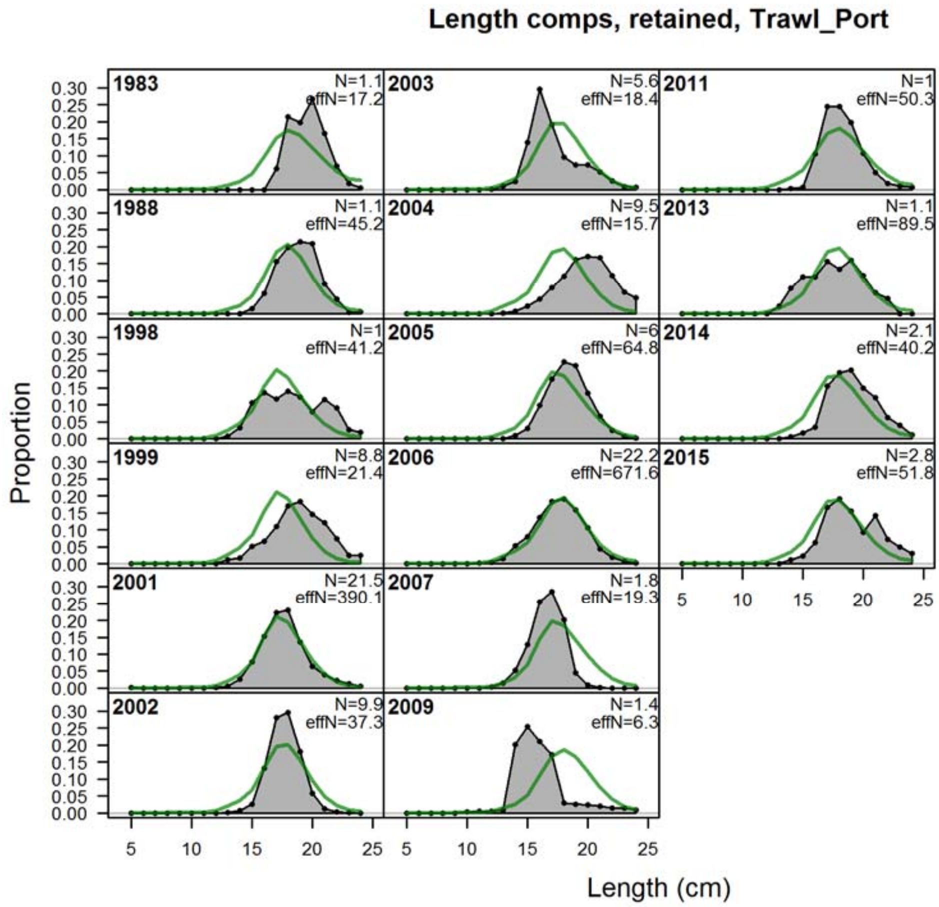

Figure A 15.4. School whiting length composition fits: trawl port retained.

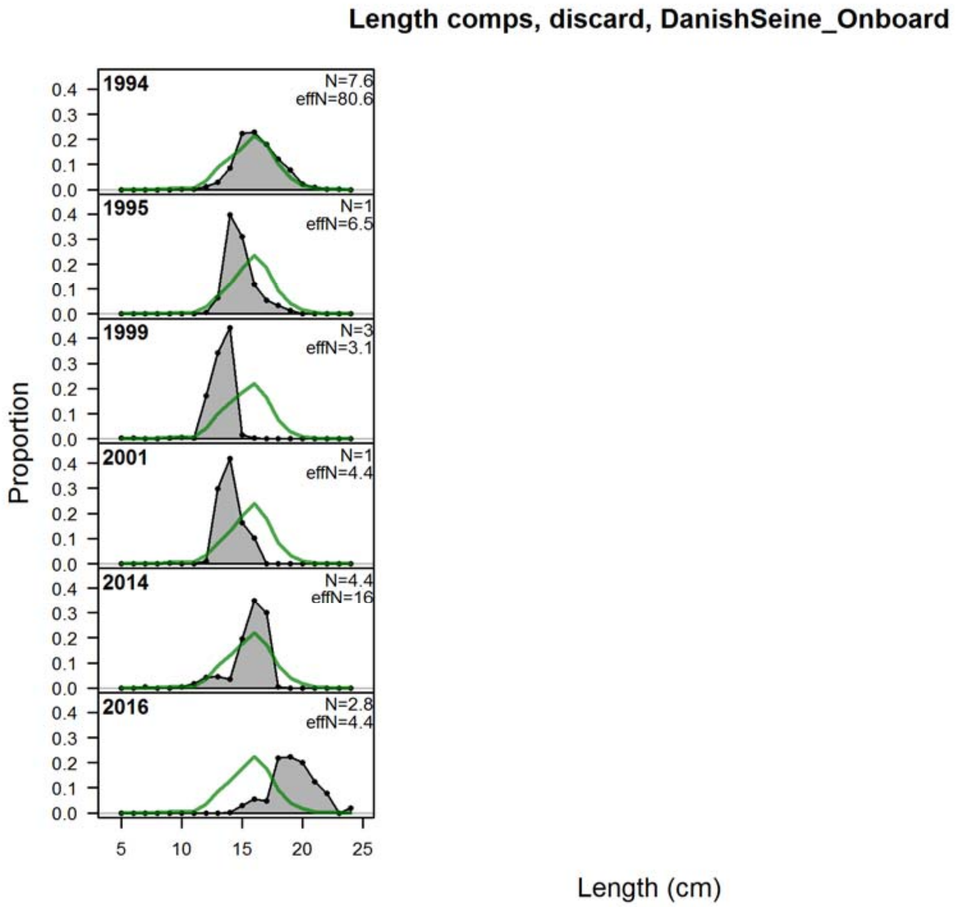

Figure A 15.5. School whiting length composition fits: Danish seine discarded.

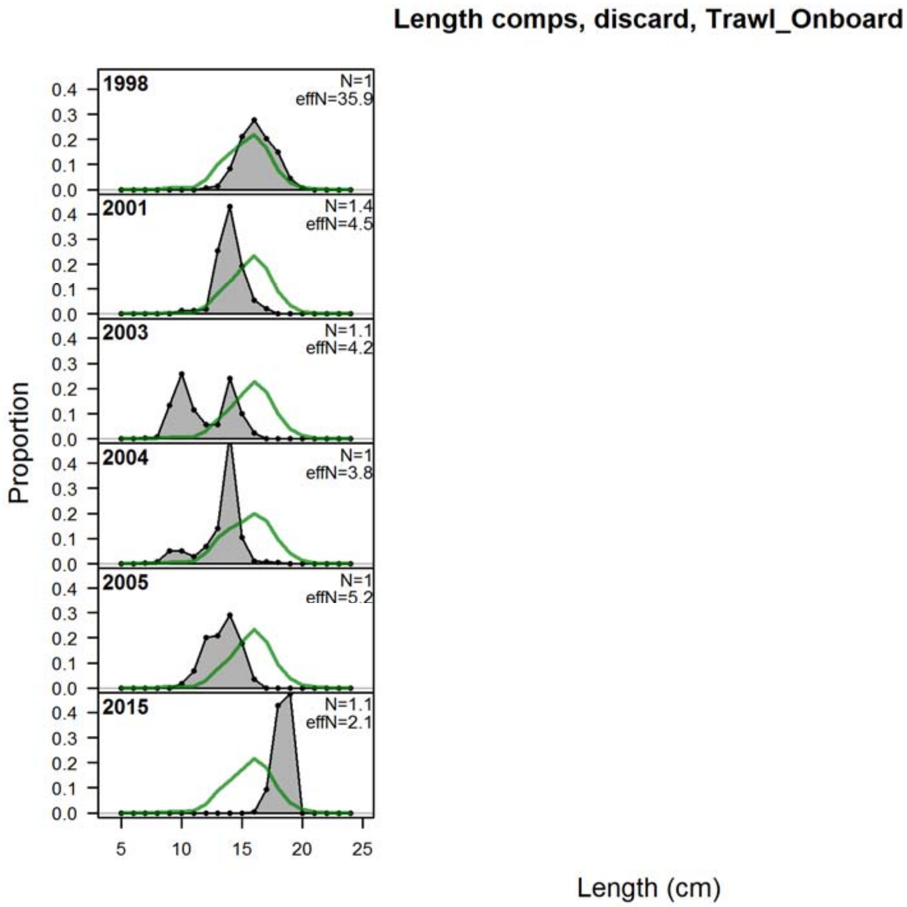

Figure A 15.6. School whiting length composition fits: trawl discarded.

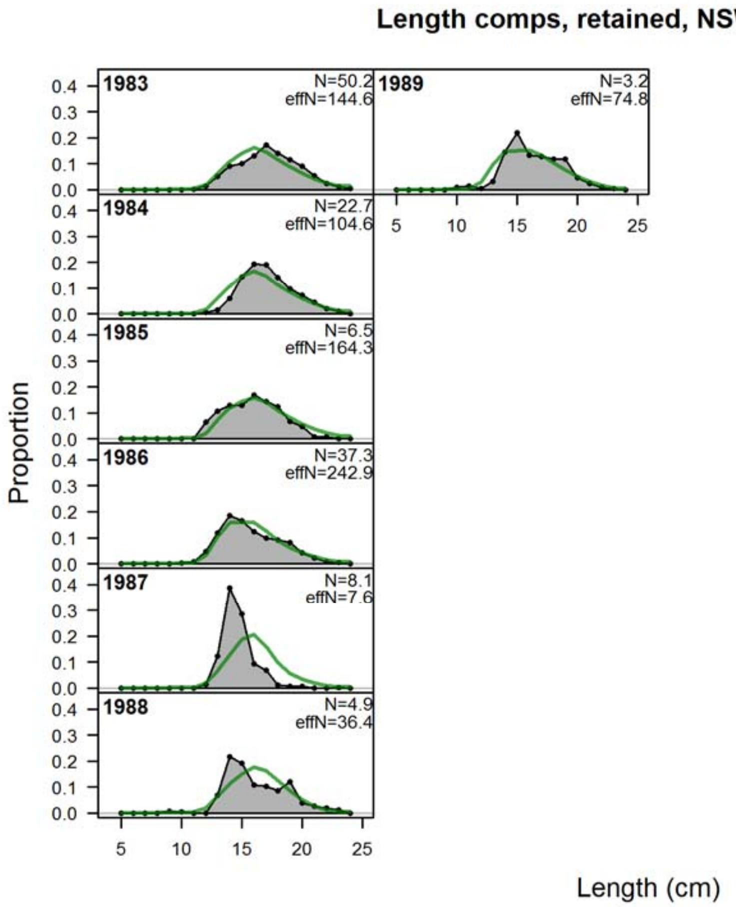

Figure A 15.7. School whiting length composition fits: NSW Danish seine port retained.

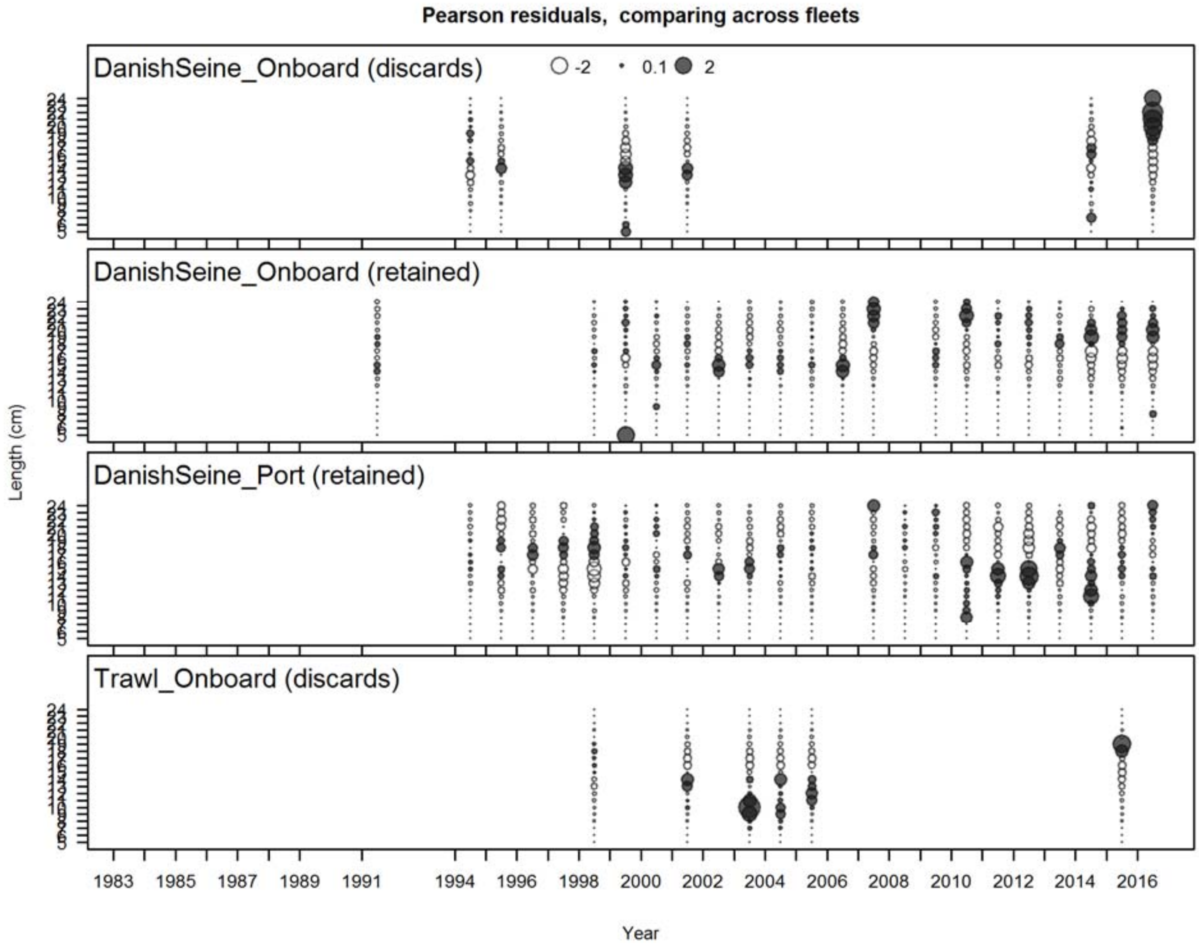

Figure A 15.8. Residuals from the annual length composition data for school whiting displayed by year and fleet for Danish seine fleets(retained and discarded) and trawl discards.

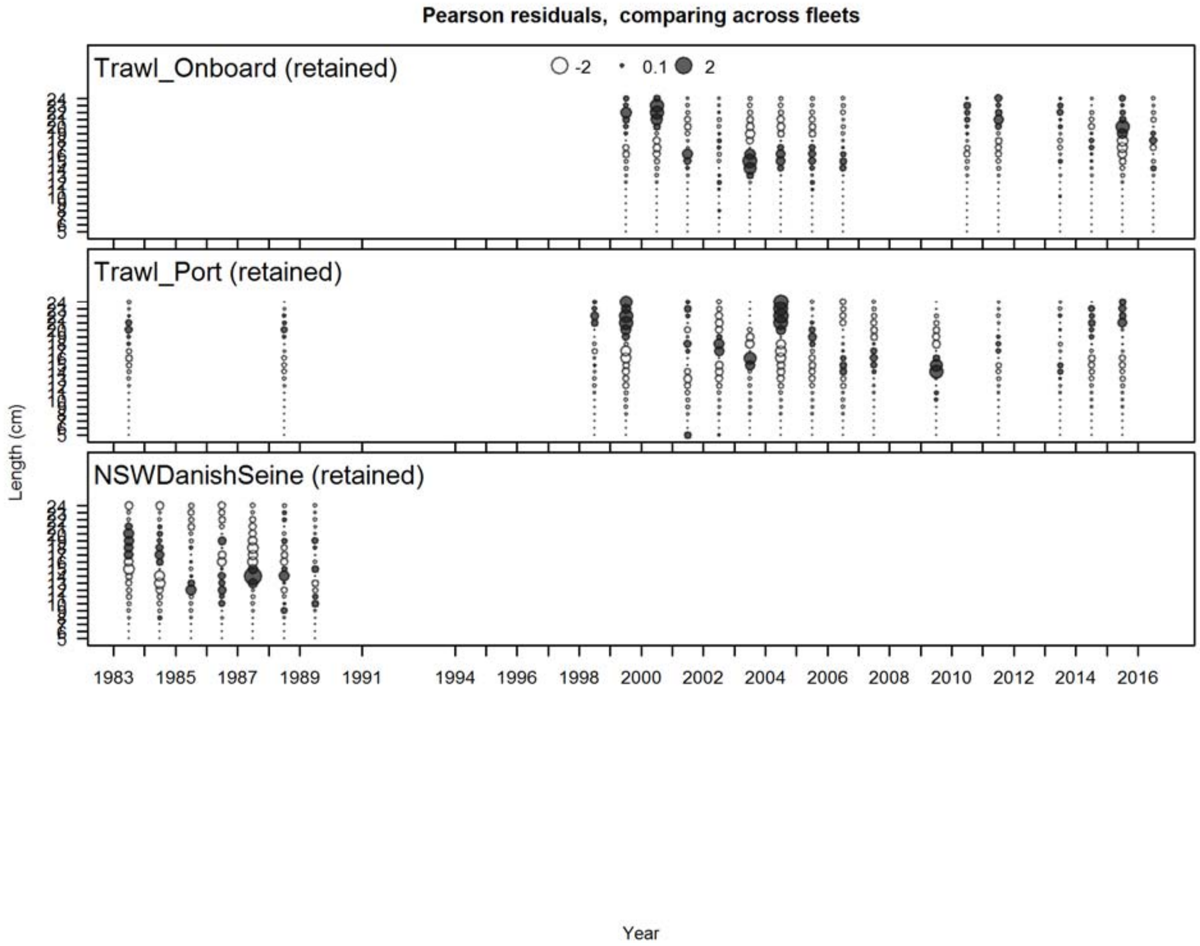

Figure A 15.9. Residuals from the annual length composition data for school whiting displayed by year and fleet for trawl (retained) and NSW Danish seine (retained).

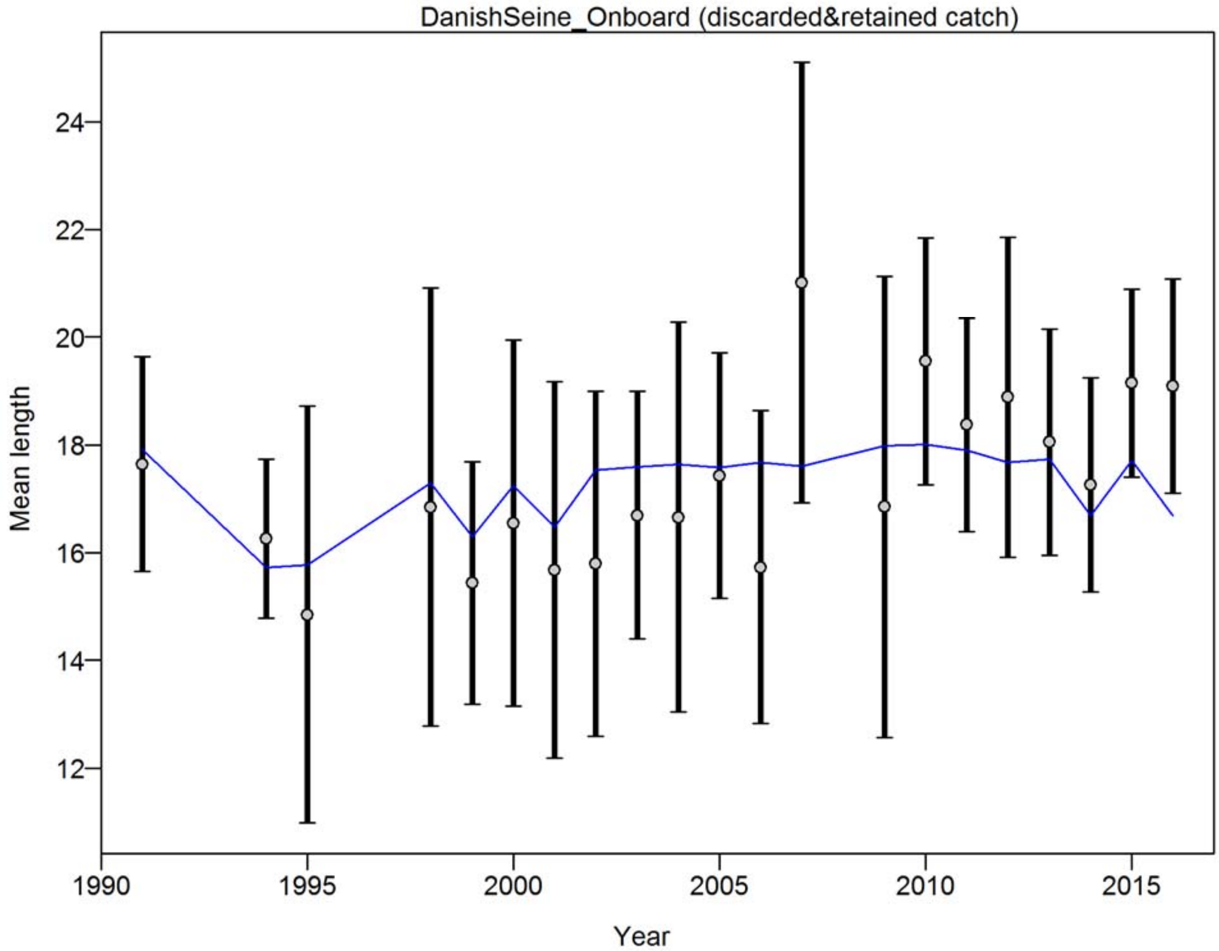

Figure A 15.10. Mean length for school whiting from Danish seine onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

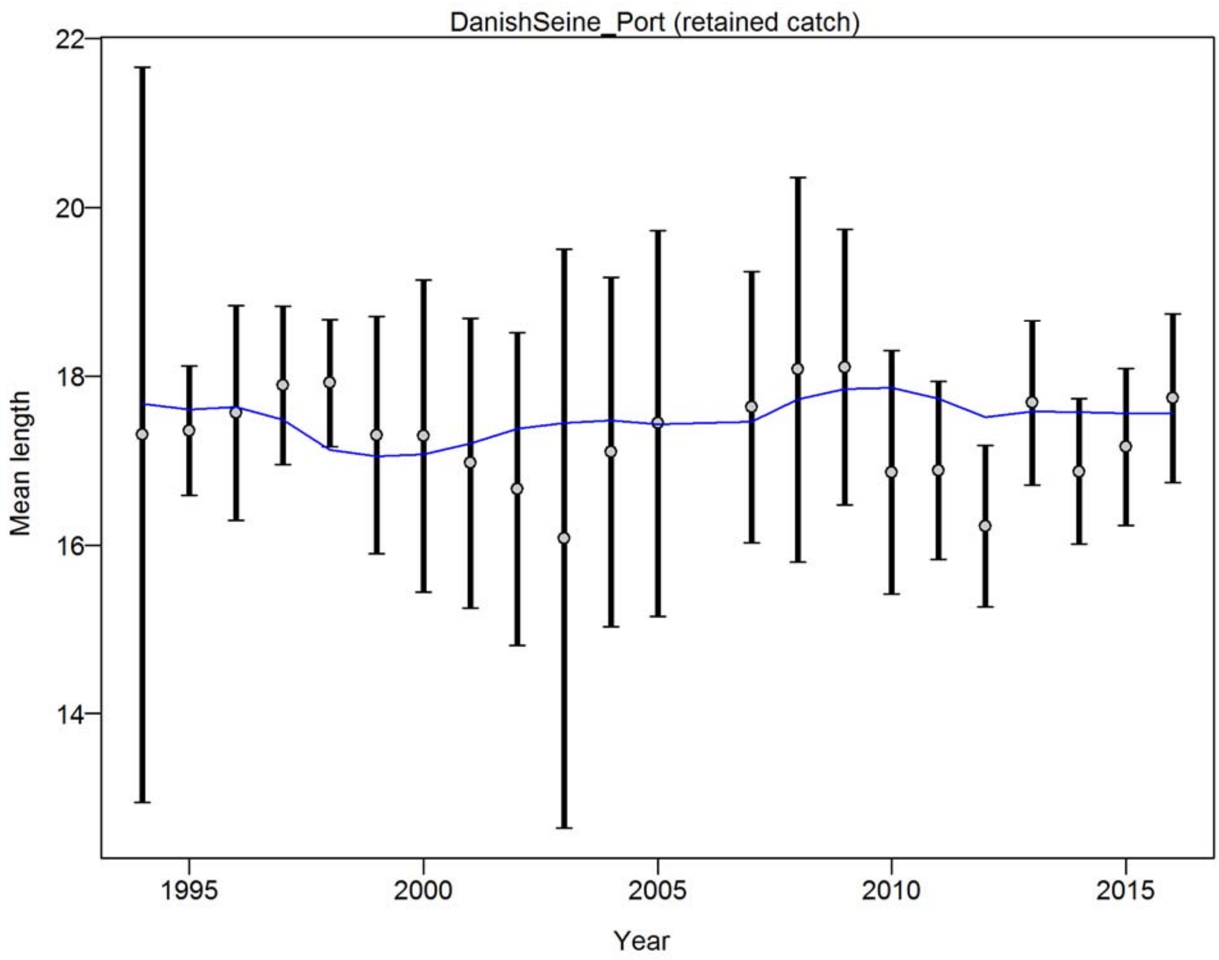

Figure A 15.11. Mean length for school whiting from Danish seine port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

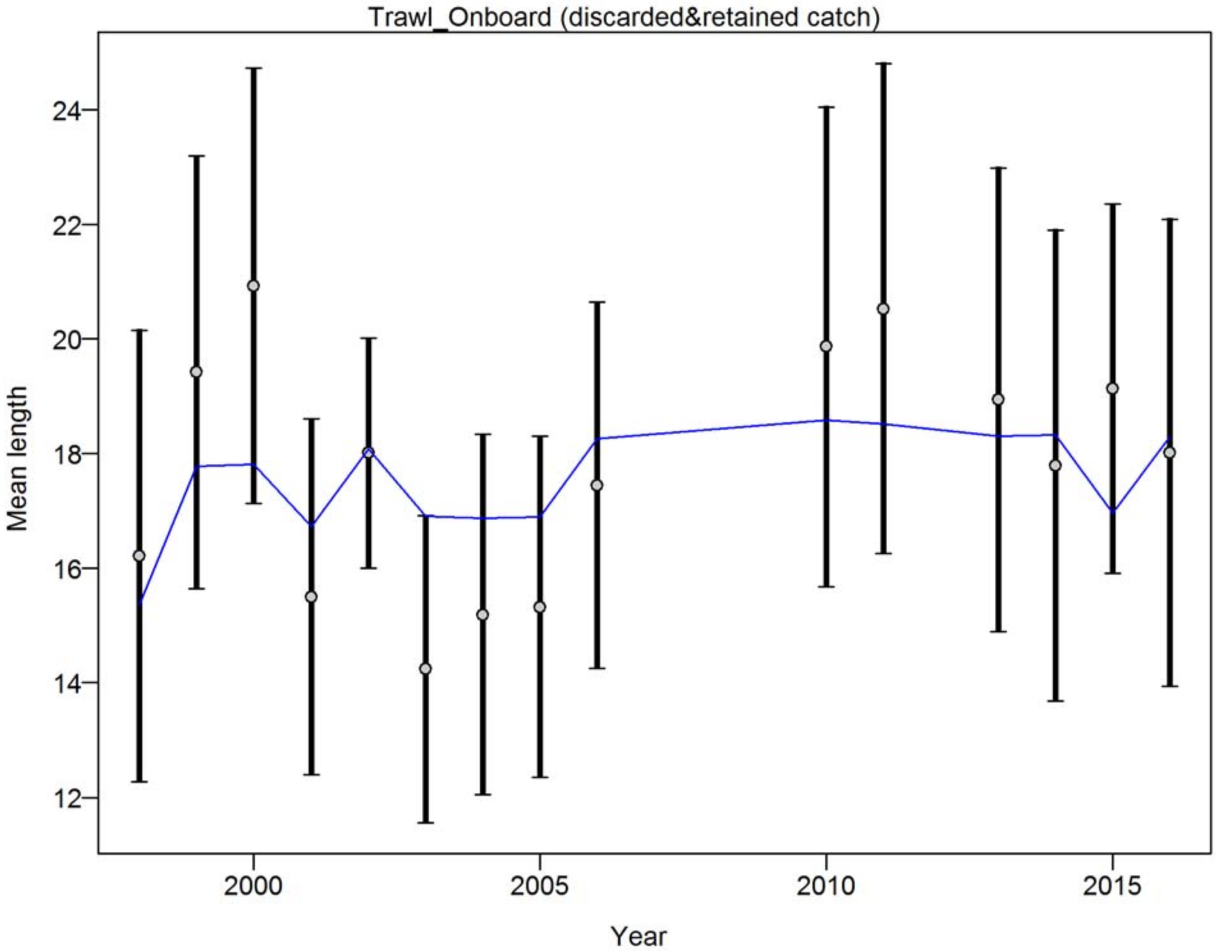

Figure A 15.12. Mean length for school whiting from trawl onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

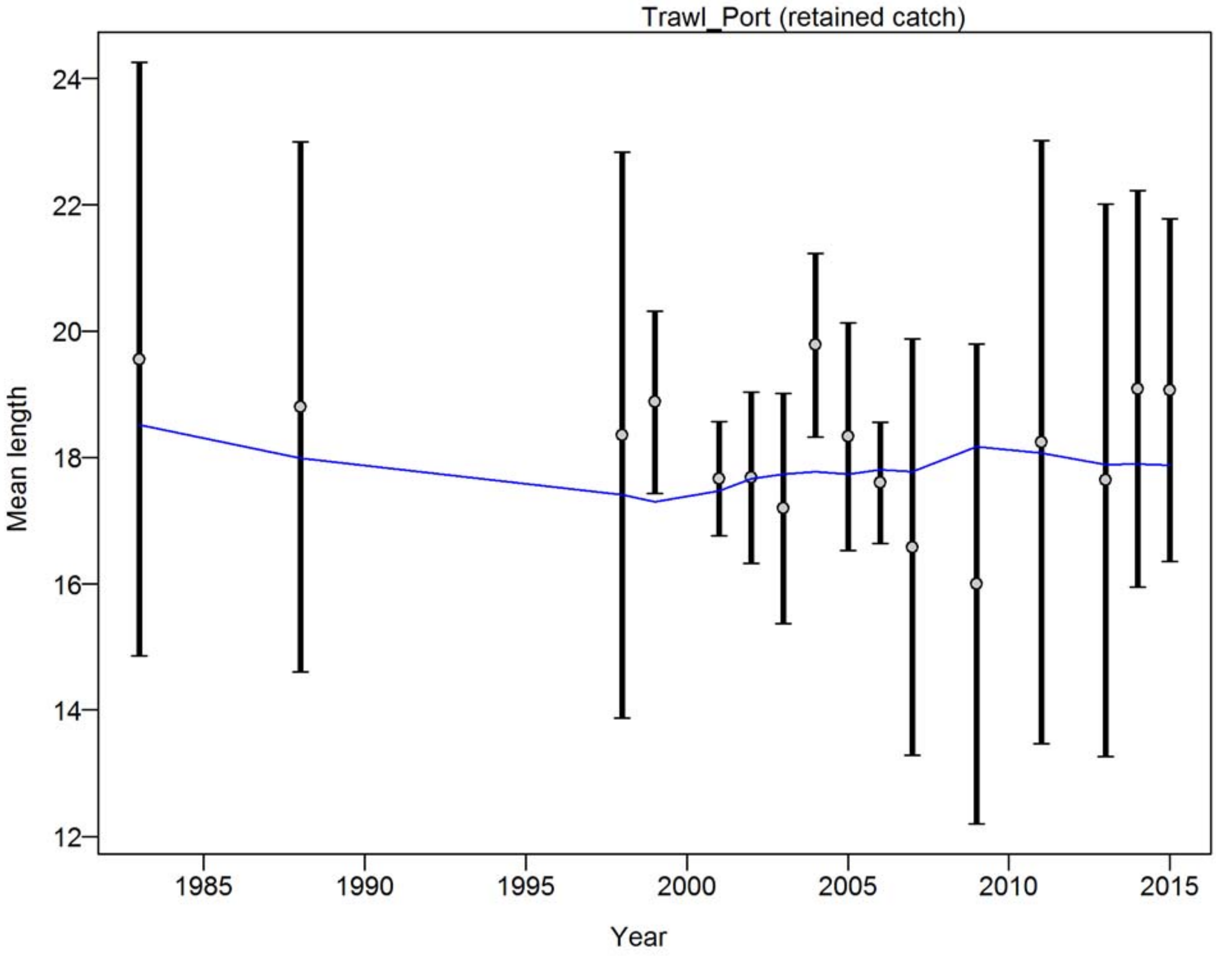

Figure A 15.13. Mean length for school whiting from trawl port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

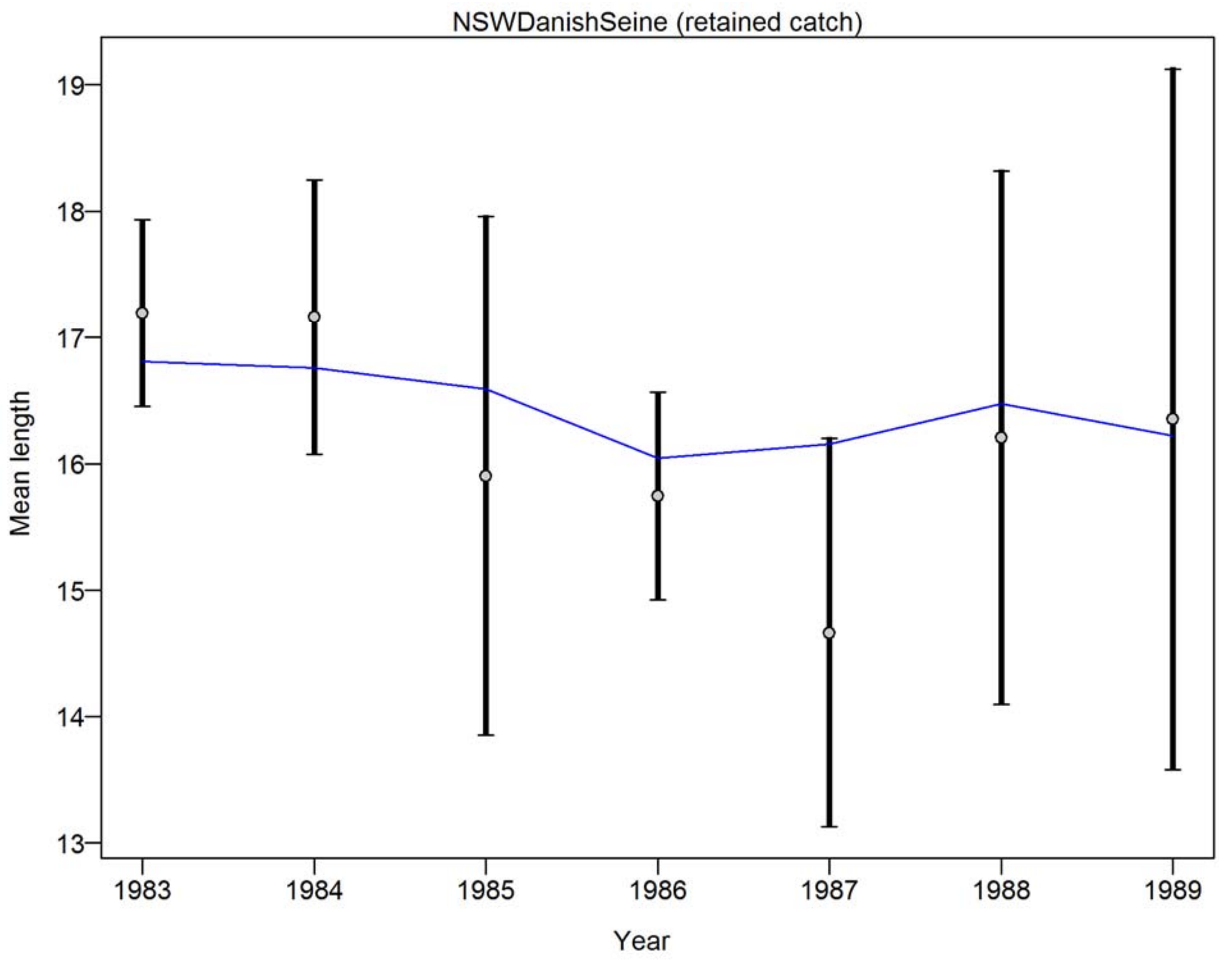

Figure A 15.14. Mean length for school whiting from NSW Danish seine with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

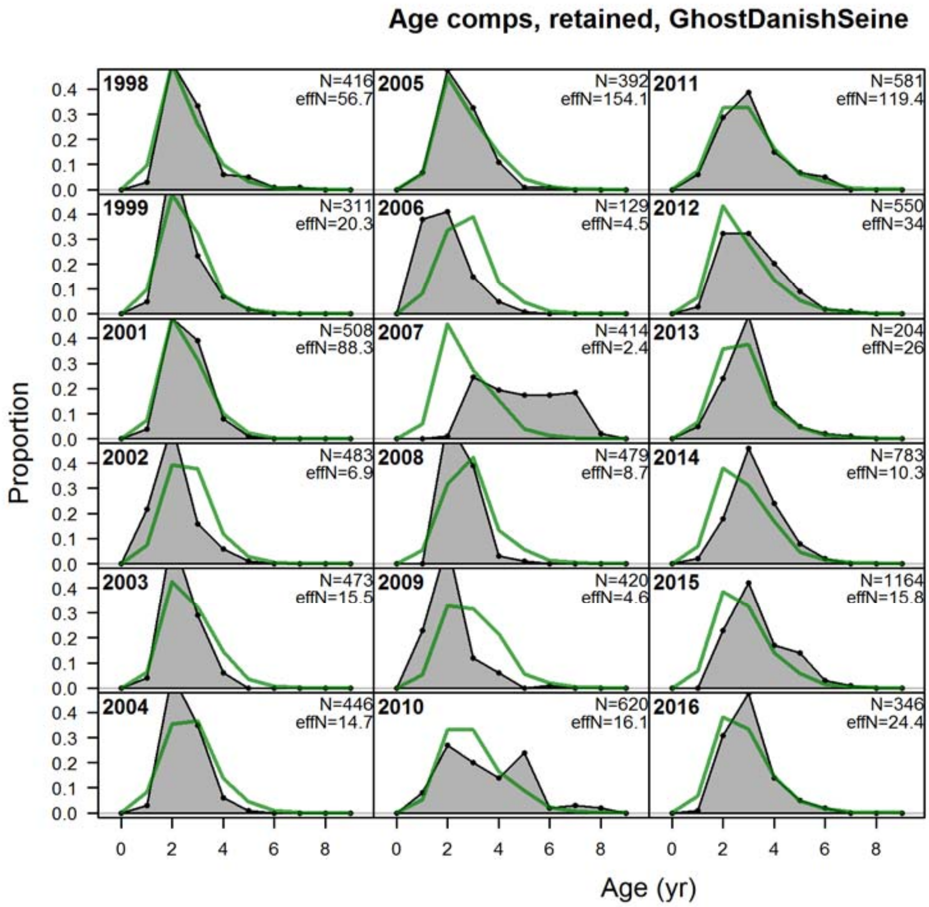

Figure A 15.15. Implied fits to age compositions for school whiting Danish seine onboard (retained).

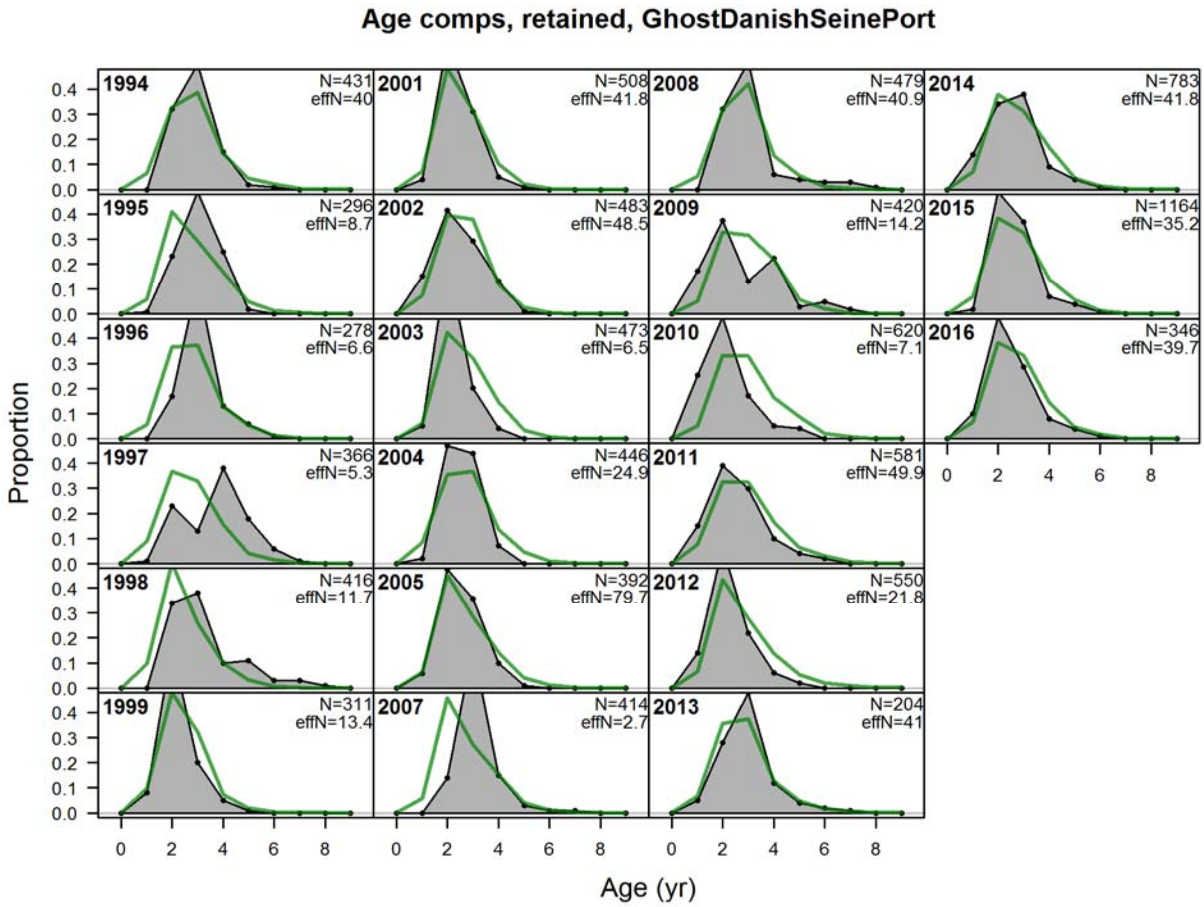

Figure A 15.16. Implied fits to age compositions for school whiting Danish seine port (retained).

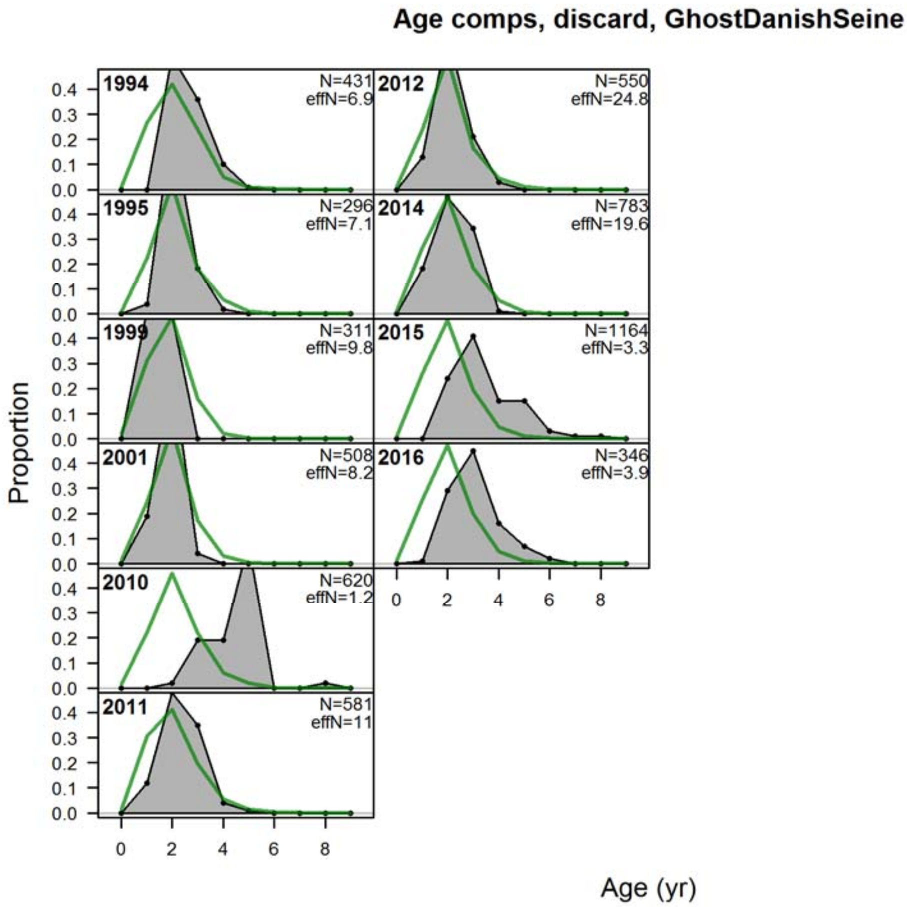

Figure A 15.17. Implied fits to age compositions for school whiting Danish seine (discarded).

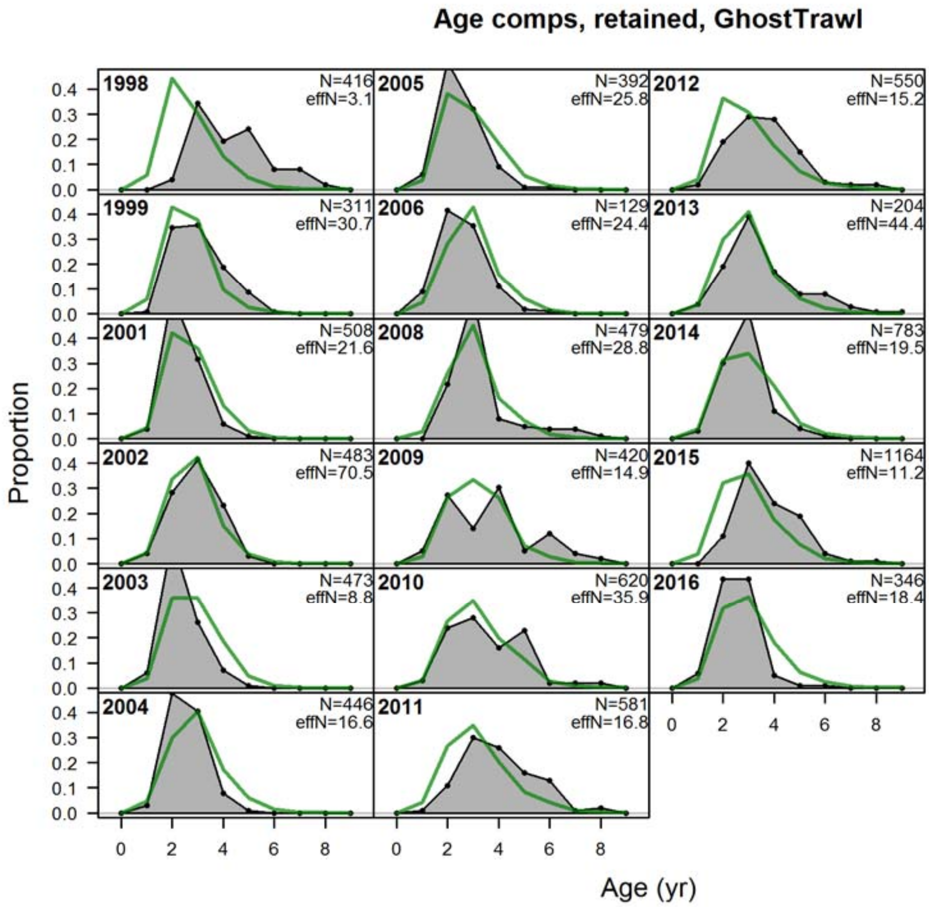

Figure A 15.18. Implied fits to age compositions for school whiting trawl onboard (retained).

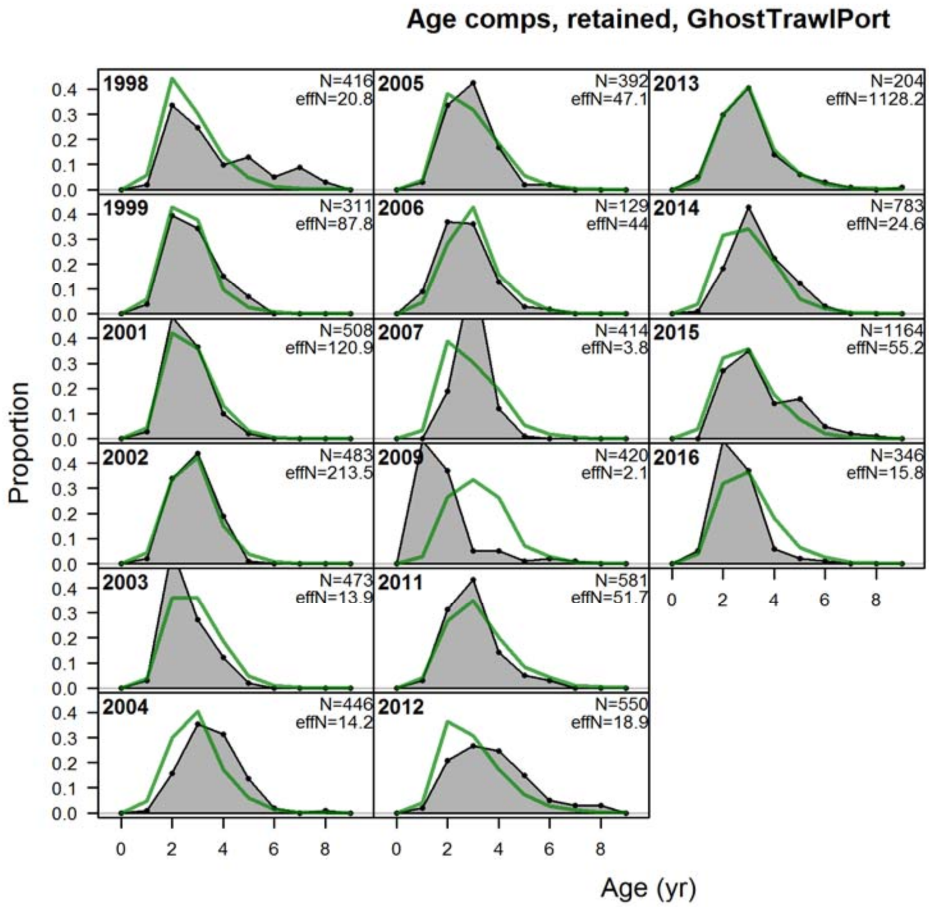

Figure A 15.19. Implied fits to age compositions for school whiting trawl port (retained).

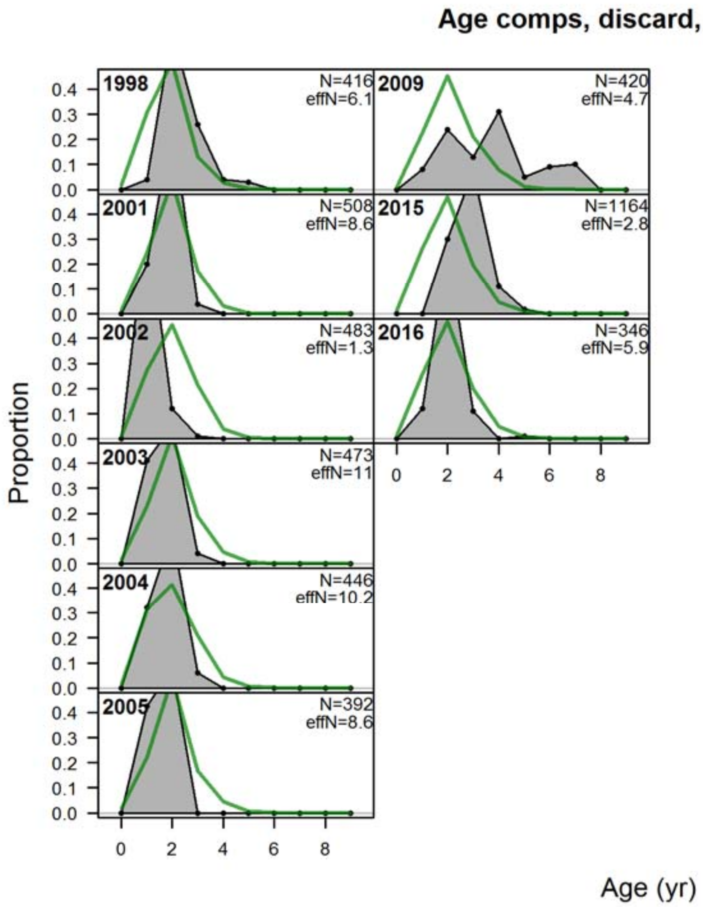

Figure A 15.20. Implied fits to age compositions for school whiting trawl (discarded).

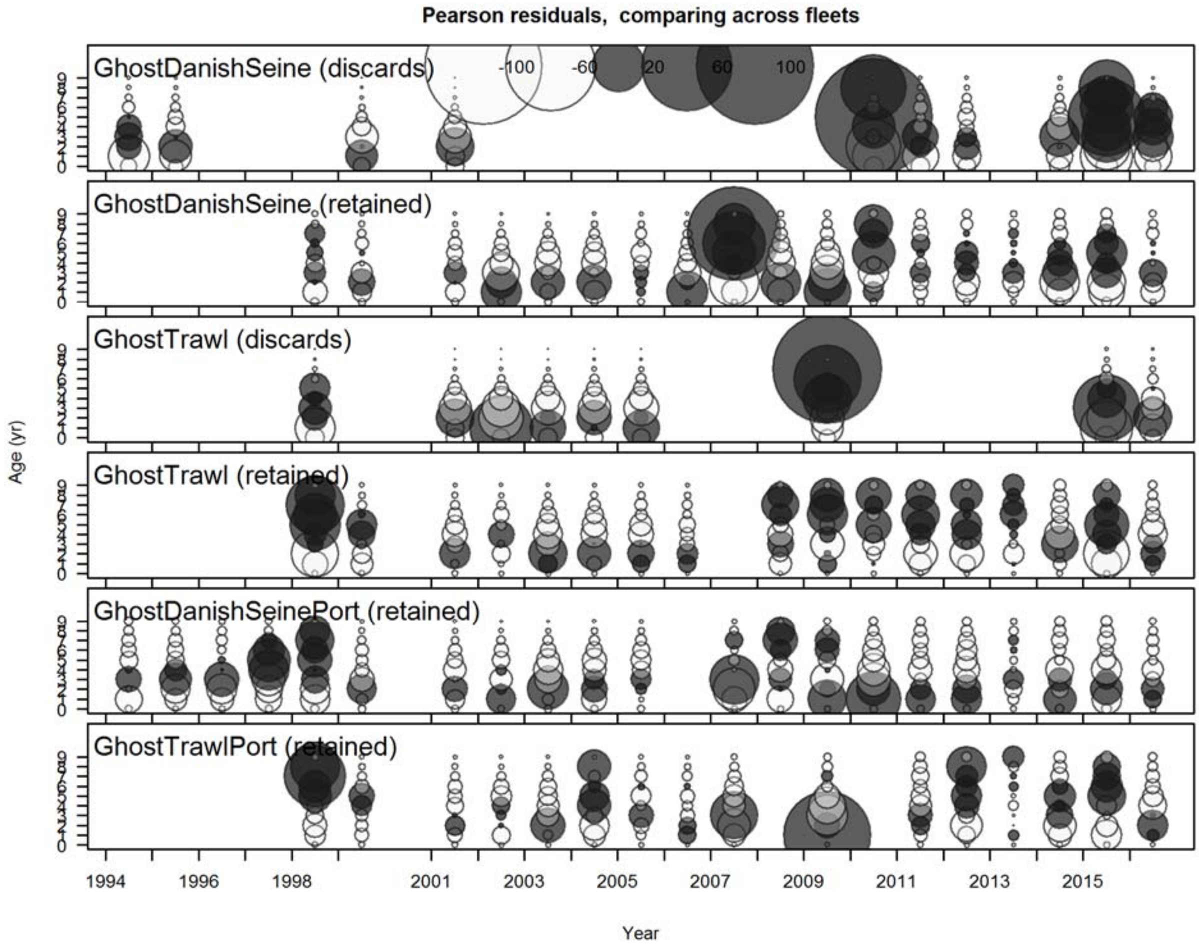

Figure A 15.21. Residuals from the Implied fits to age composition data for school whiting displayed by year and fleet.

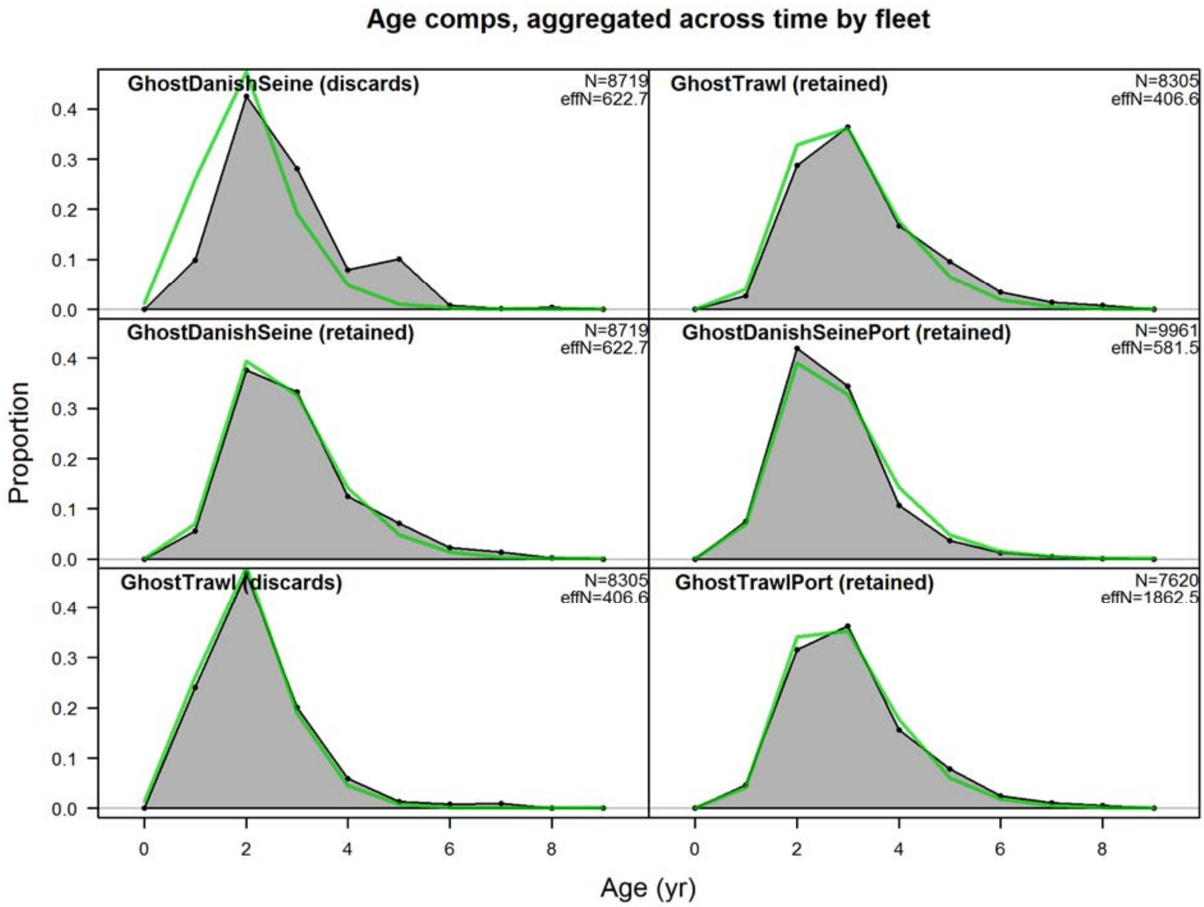

Figure A 15.22. Implied fits to age compositions for school whiting aggregated across time for each fleetl (retained and discarded shown separately).

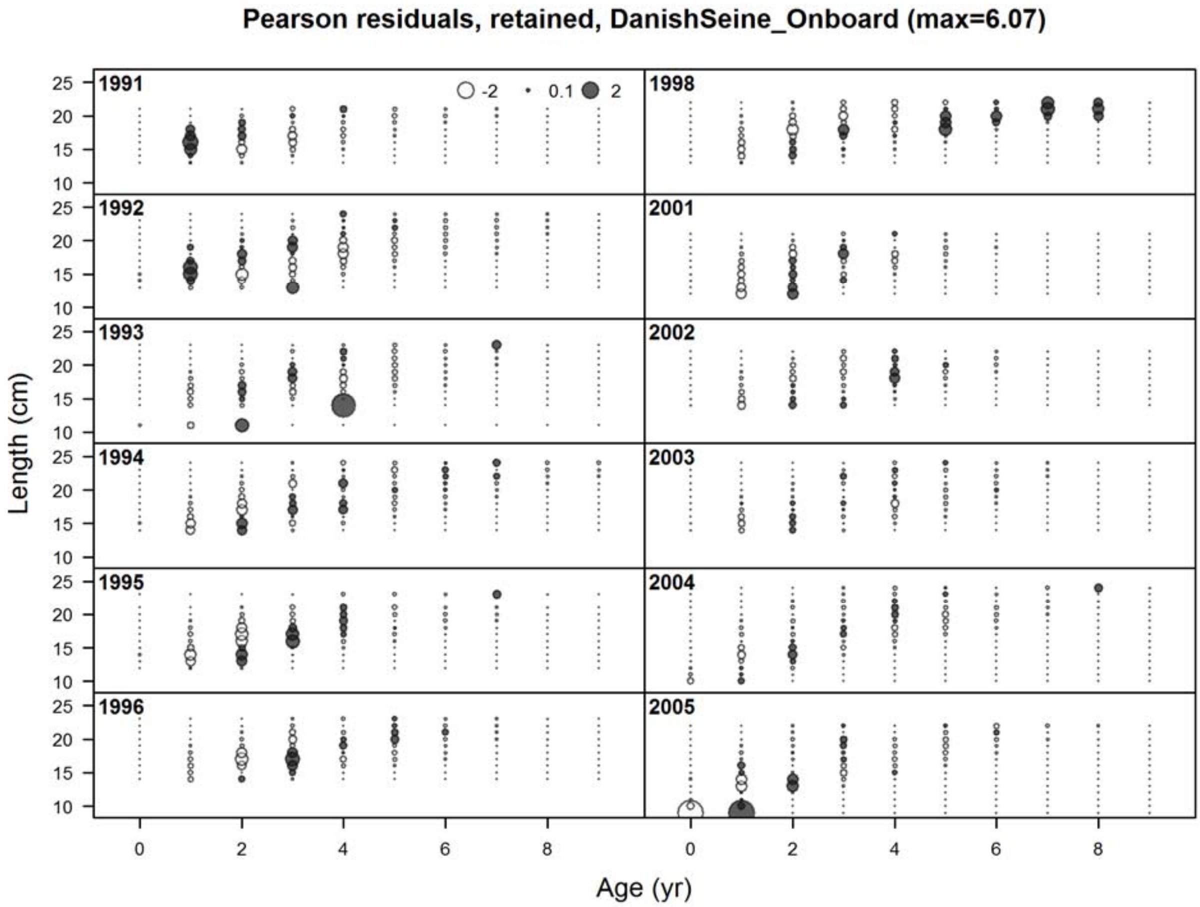

Figure A 15.23. Residuals from the fits to conditional age-at-length for Danish seine to 2005. This plot gives some indication of the variability in the age samples from year to year.

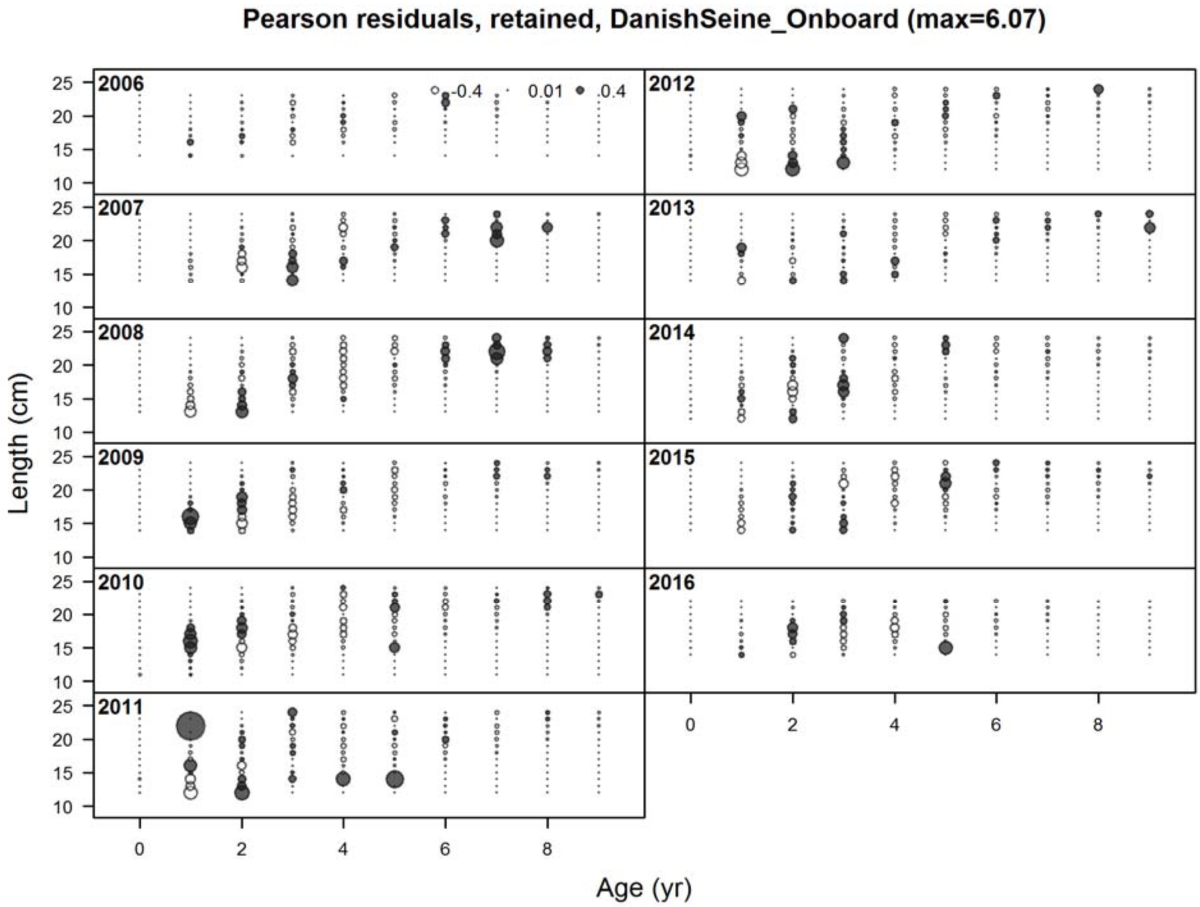

Figure A 15.24. Residuals from the fits to conditional age-at-length for Danish seine from 2006. This plot gives some indication of the variability in the age samples from year to year.

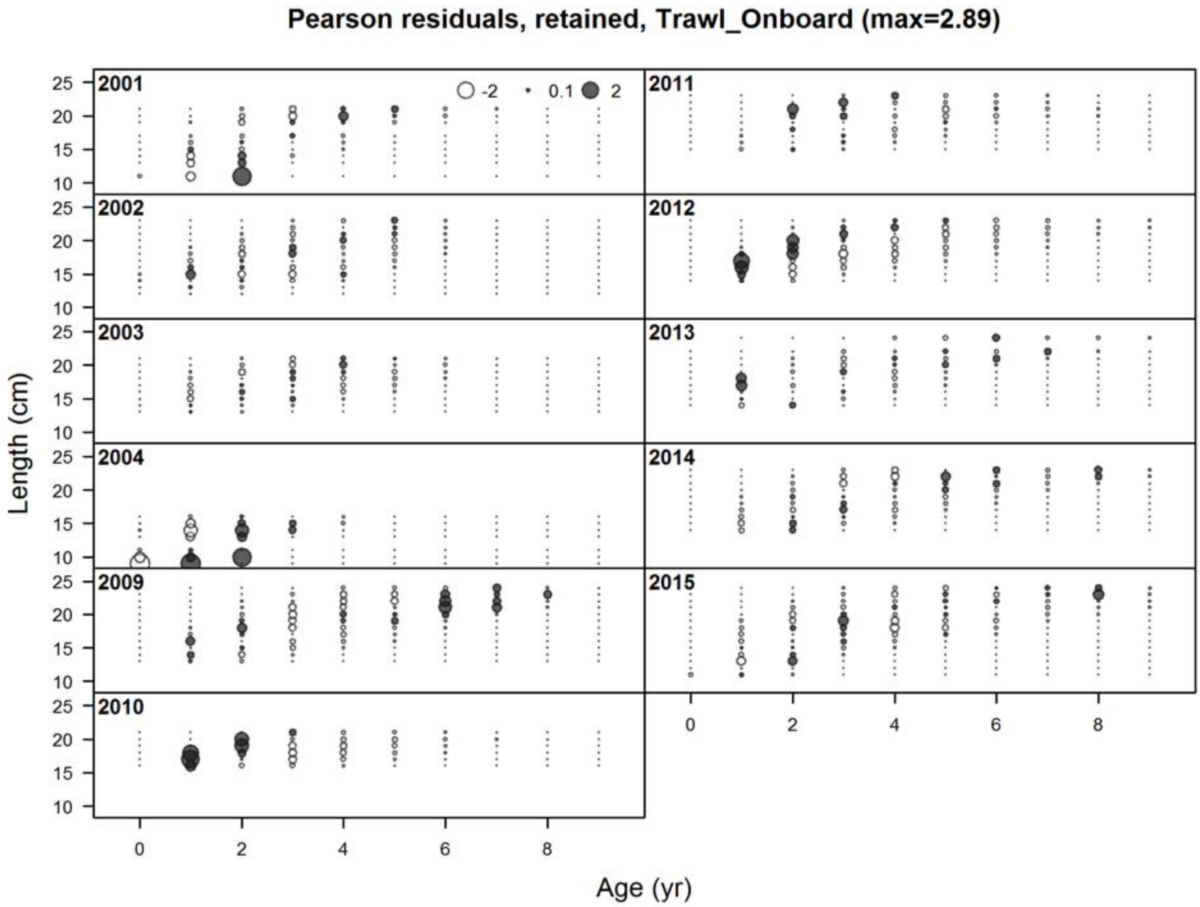

Figure A 15.25. Residuals from the fits to conditional age-at-length for trawl. This plot gives some indication of the variability in the age samples from year to year.

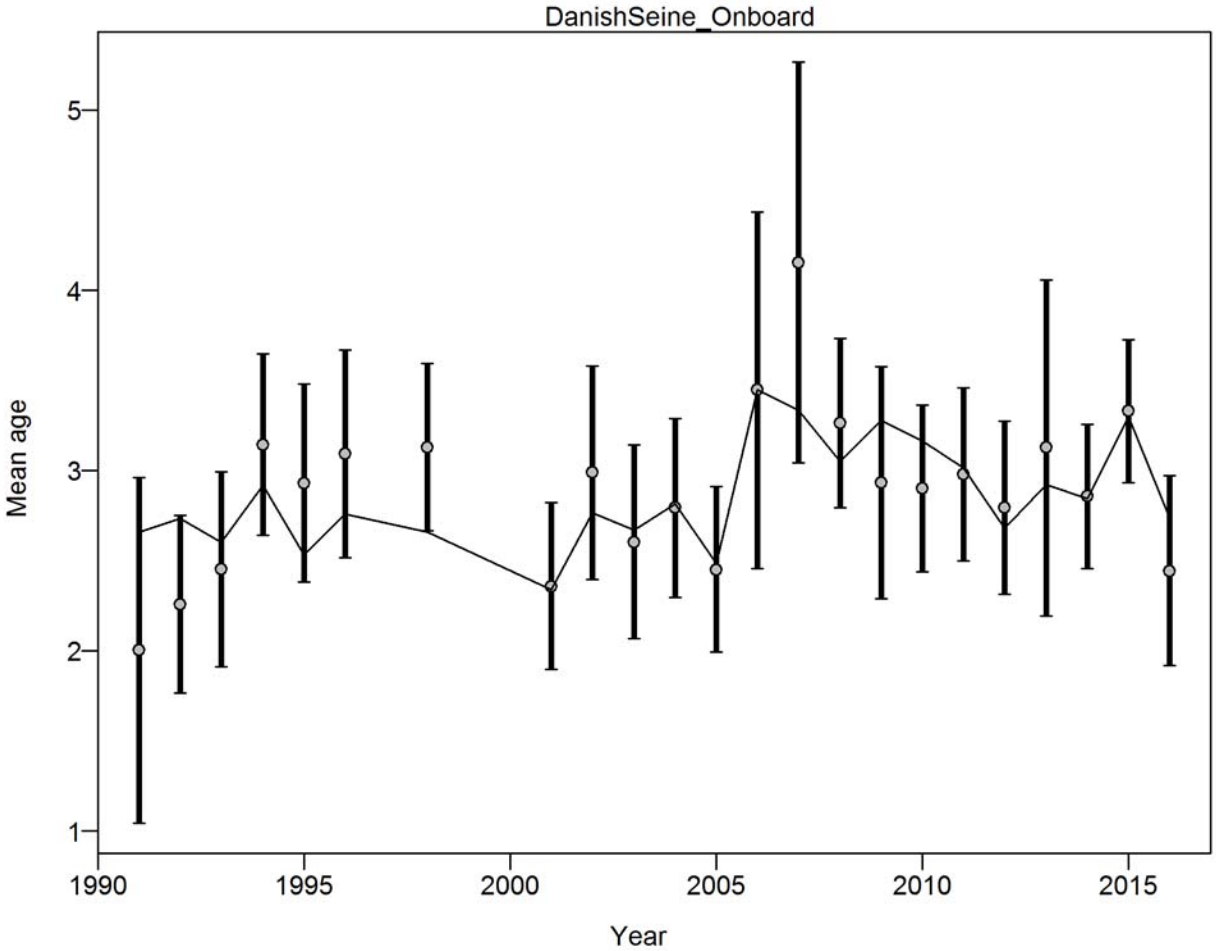

Figure A 15.26. Mean age (aggregated across length bins) for school whiting from Danish seine with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period (e.g. 2005-2007).

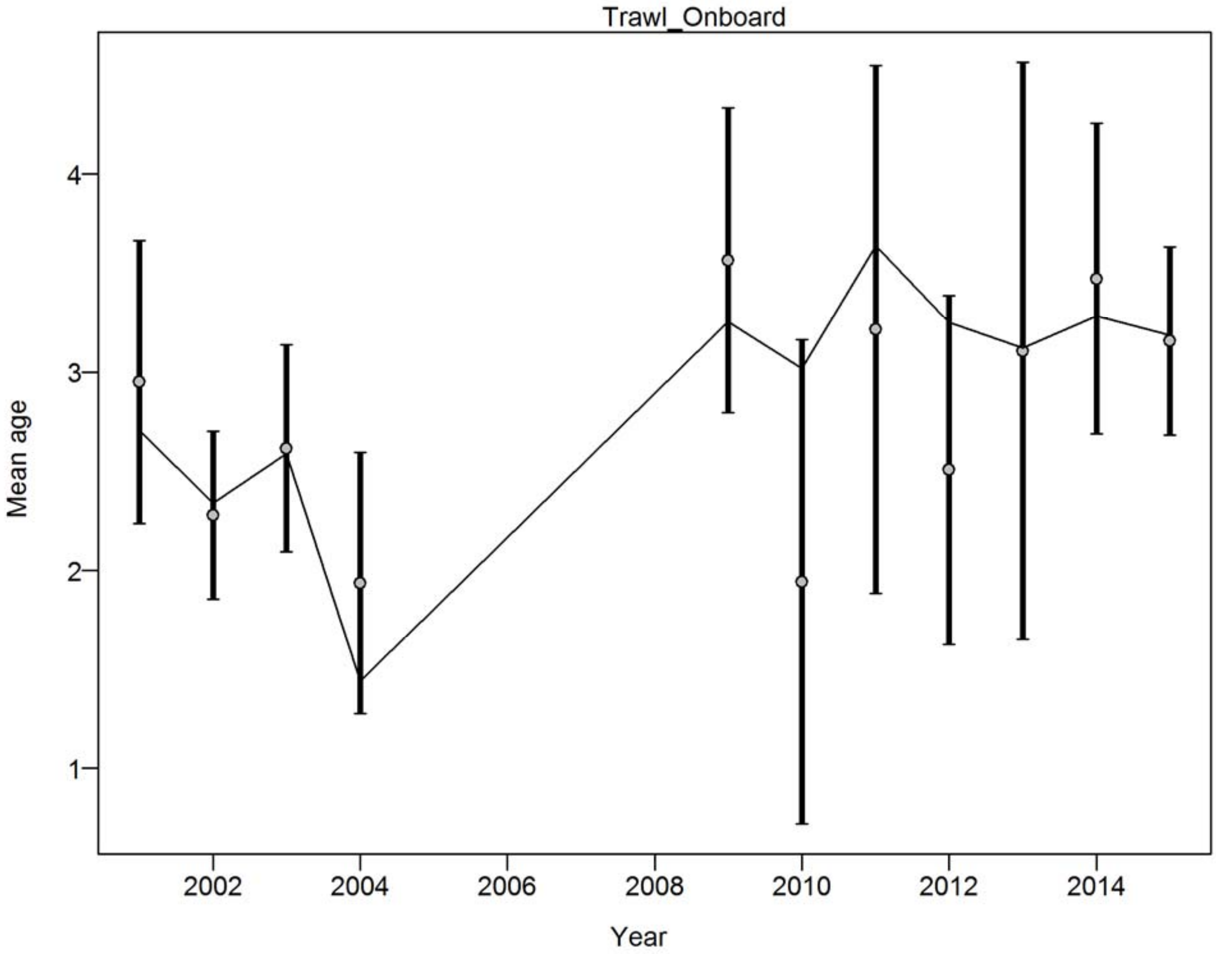

Figure A 15.27. Mean age (aggregated across length bins) for school whiting from trawl with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period (e.g. 2009-2010).