Cite as:

Day Jemery, Hall Karina, Bessell-Browne Pia and Sporcic Miriana (2020) School Whiting (*Sillago flindersi*) stock assessment based on data up to 2019. For discussion at SERAG, December 2020

OCEANS AND ATMOSPHERE
www.csiro.au

School Whiting (*Sillago flindersi*) stock assessment based on data up to 2019

Jemery Day[1], Karina Hall[2], Pia Bessell-Browne[1] and Miriana Sporcic[1]
[1] CSIRO Oceans and Atmosphere, Castray Esplanade, Hobart TAS 7000, Australia
[2] NSW Department of Primary Industries, 2 Bay Drive, Coffs Harbour NSW 2800, Australia
For discussion at SERAG, 9 December 2020.

Australian Fisheries Management Authority

Version 1.01 – 9 December 2020.

Citation

Day Jemery, Hall Karina, Bessell-Browne Pia and Sporcic Miriana (2020) School Whiting (*Sillago flindersi*) stock assessment based on data up to 2019. For discussion at SERAG, December 2020.

Copyright

Important disclaimer

Contents

Figures

Tables

Acknowledgments

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, Robin Thomson and Paul Burch (all from CSIRO) pre-processed the data. Malcolm Haddon provided useful code for automated iterative reweighting, Athol Whitten provided useful R code for organising plots. Geoff Tuck (CSIRO), Ian Taylor (NOAA) and Chantel Wetzel (NOAA) are thanked for helpful discussions on this work. Paul Burch provided updated ageing error matrices. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models. Thanks to Ian Taylor for his patient advice on using this package and for answering numerous technical questions on Stock Synthesis over a number of years.

Executive summary

This document updates the 2017 assessment of School Whiting (*Sillago flindersi*) to provide estimates of stock status in the SESSF at the start of 2021 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 (SS-V3.30.16). The 2017 stock assessment has been updated with the inclusion of data up to the end of 2019, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates. A range of sensitivities were explored.

Two preliminary base cases were presented at the October SERAG meeting. The first potential base case repeated the 2017 assessment using the same model structure, with updated data to 2019. The second alternative base case (the five-fleet base case) extended this model by incorporating two additional NSW fleets and additional NSW CPUE, discarding, length, conditional age-at-length and ageing error data.

The five-fleet base case assessment estimates that current spawning stock biomass is 41% of unexploited spawning stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2021 recommended biological catch (RBC) is 2,140 t, with the long-term yield (assuming average recruitment in the future) of 2,448 t. The average RBC over the three-year period 2021-2023 is 2,237 t and over the five-year period 2021-2025, the average RBC is 2,295 t.

Exploration of model sensitivity showed variation in spawning biomass across all sensitivities ranging from 31% to 57% of SSB_0 with greatest sensitivity to natural mortality, followed by length at 50% maturity.

A major change in the 2020 stock assessment model structure was to revise and split the NSW state catch data into three separate fleets comprising the existing NSW Danish seine fleet, and an additional two fleets: NSW trawl; and prawn trawl fleets. Catches from these additional fleets were previously included in the trawl fleet, which now comprises trawl catches from: Victorian state waters; Commonwealth waters; and NSW state waters south of the Barrenjoey line. The NSW trawl fleet only comprises data from NSW trawlers operating north of the Barrenjoey line, with catches from prawn trawlers in this same region allocated to the separate prawn trawl fleet.

Along with updated data from 2017-2019 from the Commonwealth fishery and these structural changes to the catch series and updated data from 2017-2019 from the Commonwealth fishery, moving from a three-fleet model used in previous assessments to a five-fleet model, new data was included from NSW state waters for both the NSW trawl fleet and the prawn trawl fleet including: CPUE data; discard rates; length frequency data; conditional age-at-length data; ageing error. Natural mortality was unable to be estimated in the five-fleet model so this parameter is fixed in this model at 0.6 yr^{-1}.

Despite these structural modifications to the model, data updates and an increase in historical data available to the assessment, the five-fleet base case assessment produces results consistent with those from the 2017 assessment, albeit with much tighter confidence bounds on the estimates of spawning stock status.

1 Introduction

1.1 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 (Gray *et al.* 2014a,b). 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 to four years of age, depending on the gear type used. Selectivity of 50% is achieved somewhere between one and two years of age for the prawn trawl fleet, at around two years of age for the Danish seine fleets and between three and four years for the trawl fleets. Selectivity for two-year old fish is less than 20% for the trawl fleets, and for one-year old fish is less than 10% for all fleets except for the prawn trawl fleet. Most of the catch from 1942-1995 was taken using Danish seine (mainly in zone 60 of the SESSF - Bass Strait). Since 1995, the catch has been around 40% Danish seine (including Commonwealth and state fleets), 30% prawn trawl (from NSW) and 30% otter trawl (including both Commonwealth and state fleets). In contrast to the Danish seine catches, catches by otter trawl occur predominantly in SESSF zone 10 and in state waters north of the Barrenjoey line, 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 was 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 2020 assessment are shown in Table 1, Table 2, Figure 1 (separated by fleet) and Figure 2 (separated by jurisdiction). Catches of School Whiting first exceeded 1,000 t in 1981 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 1981, with the catches slowly declining from the 1990s to 2015. Catches from 2008 to 2014 ranged between 1,200 and 1,400 t, then between 1,400 and 1,500 t from 2015 to 2016, then increasing to range between 1,750 and 2,000 t from 2017 to 2019 (Figure 1, Table 1, Table 2). From 1986-1995, more than 50% of the catch was taken by Commonwealth registered vessels, dropping to around 35% in the period 1997 to 2013, then increasing to around 50% from 2014 to 2016, and declining to around 30% from 2017 to 2019 (Figure 2). Catches of School Whiting taken by state registered vessels comprised more than 50% of the total catch for the period 1997-2013 and have ranged between 40% and 50% from 2014 to 2016 and between 60% and 70% from 2017 to 2019 (Figure 2). Discard percentages are variable and appear market driven (Figure 3, Table 4).

The Commonwealth Total Allowable Catch (TAC) was initially set at 2,000 t in 1993, then reduced to 1,500 t in 1999 until 2006 (Figure 2, Table 3). In 2007 this was reduced to 734 t, then 750 t in 2008 and increased to 1125 t in 2009 (Figure 2, Table 3). Since 2010 the Commonwealth TAC has varied between 600 and 1,000 t (Figure 2, Table 3). The total landed catch (state and Commonwealth) averaged 1,350 t in the period 2004 to 2016, ranging between 1,200 t and just over 1,500 t (Table 2). This catch total increased to an average over 1,800 t recently, in the period 2017 to 2019 (Table 2). From 1994-2003, the total landed catch averaged over 1,700 t (Table 2). The total state catch averaged around 750 t between 2008 and 2016, following an average of around 1,000 t in the decade 1998-2007 (Table 2). The average state catch since 2017 has again risen to around 1,200 t (Table 2).

1.2 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 (Smith and Wayte, 2005). Stout whiting (*Silllago 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. Data adjustments are made to reported catch and effort data from NSW state waters before CPUE standardisations and inclusion in this assessment, to assign historical mixed Eastern School Whiting and Stout Whiting catches to separate species and correct known species misreporting in northern NSW waters (Hall 2021).

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 since the late 1980s. Modern markers and a new study would help to clarify the population structure in this species (A, Moore, pers. comm.).

1.3 Previous assessments

A partial assessment update was conducted in 2019, following increases to the state component of the catch in NSW waters in 2017 and 2018. This assessment updated the previous stock assessment (Day 2017) by updating only the catch and CPUE data to 2018. The last full stock assessment for School Whiting was conducted in 2017 using data up to 2016 (Day 2017). This was an update of the 2009 assessment (Day 2009), which in turn extended the 2008 (Day 2008) and 2007 assessments (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 3,785t 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 spawning stock biomass (SSB_{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.

The most recent stock assessment (Day 2017) using Stock Synthesis version SS-V3.30.08.03, (Methot et al., 2017) incorporated 8 additional years of data since the previous assessment and estimated the 2018 spawning stock biomass to be 47% of unexploited spawning stock biomass (SSB_0), with an RBC of 1,606 t and a long-term yield of 1,641 t. The 2019 update revised the 2018 estimate of spawning stock biomass from 47% to 36%, as a result of increased catches and a downward trend at the end of the updated CPUE series.

1.4 Modifications to the previous assessments

The 2020 assessment uses Stock Synthesis version SS-V3.30.16, (Methot *et al.* 2020), updated from version SS-V3.30.08.03, (Methot *et al.* 2017) that was used in the 2017 assessment. New catch, discard, length and conditional age at-length data is available from the three-year period from 2017-2019. Conditional age-at-length data used in the 2020 assessment is again based on ageing of sectioned otoliths, after whole otolith readings were replaced in the 2017 assessment, when it became apparent that readings from sectioned otoliths were more reliable than those from whole otoliths, and also produced a larger maximum age. A selection of historical whole otoliths was sectioned and re-aged prior to the 2017 assessment to provide a consistent dataset through time. 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).

In addition to the updates to these data, the NSW state catch data was split into three separate fleets comprising the existing NSW Danish seine fleet, and an additional two fleets: NSW trawl; and prawn trawl fleets. Catches from these additional fleets were previously included in the trawl fleet, which now comprises trawl catches from: Victorian state waters; Commonwealth waters; and NSW state waters south of the Barrenjoey line. Data from NSW registered trawlers south of the Barrenjoey line are subsumed within the existing trawl fleet, given that many of the southern NSW vessels have dual Commonwealth and state licences. The NSW trawl fleet only comprises data from NSW state registered trawlers operating north of the Barrenjoey line using otter trawl gear, with catches from prawn trawlers in this same region allocated to the separate prawn trawl fleet. Along with these structural changes to the catch series, moving from a three-fleet model used in previous assessments to a five-fleet model, new data was included from NSW state waters for both the NSW trawl fleet and the prawn trawl fleet including: CPUE data; discard rates; length frequency data; conditional age-at-length data; ageing error, in addition to updated data from 2017-2019 from the Commonwealth fishery.

1.4.1 Data-related issues

1. As in the 2017 assessment, length-frequency data for each fleet are included separately from onboard sampling and port-based sampling. 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 (Sporcic 2020) from 1986-2019 using Commonwealth logbook records. This series, along with the series for the trawl fleet (Sporcic 2020), also based on Commonwealth logbook records, is constructed from individual shot by shot analysis of catch and effort.
4. Four new standardised CPUE time series are included using NSW data. There are two separate series for each of the NSW trawl fleet and the prawn trawl fleet, with one series based on a relatively coarse monthly catch and effort records from 1998-2008 and a higher resolution second series based on daily catch and effort records from 2010-2019. Ideally, this analysis would be based on shot by shot records, but these data are not available for these fleets.
5. State catches have been added to catches from the appropriate fleets with considerable revision of the historical NSW state catch, including previously unavailable catches in the period 1942-1946. The new model now has a start year of 1942, rather than 1947, as used in the 2017 assessment.
6. The ageing error matrix has been updated for ageing data collected in the Commonwealth fishery and a new ageing error matrix has been estimated for the NSW state ageing data.
7. Commonwealth catch, discard, length-composition, age-at-length, and catch rate data have been added for the period 2017-2019.
8. NSW catch data has been split between four fleets: trawl, NSW Danish seine, NSW trawl and prawn trawl, according to gear type used and for trawl fleet, the area where fishing occurred (north or south of the Barrenjoey line).
9. NSW discard data has been included for the NSW trawl and prawn trawl fleets for the period 1990-1995 and 2014-2019.
10. NSW length data has been included separately for the NSW Danish seine, NSW trawl and prawn trawl fleets, with individual years of early length frequency from as far back as 1951, 1971 and 1974 and a range of years with length frequency distributions between 1982 and 2019. This largely comprises length data north of the Barrenjoey line.
11. NSW age data has been included from 2015-2016 for the NSW Danish seine, NSW trawl and prawn trawl fleets and from 2005-2007 for the prawn trawl fleet only.

1.4.2 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.
2. Unlike the 2017 assessment, natural mortality, *M*, is now fixed within the model, based on both a likelihood profile, which indicates there was little information in the data to inform the estimate of *M*, and the biologically unreasonably valuable obtained when *M* is estimated within the model.
3. Recruitment residuals are estimated from 1981-2016, with the last recruitment event estimated three years before the most recent available data.

4. An updated tuning procedure is used to balance the weighting of each of the data sources that contribute to the overall likelihood function, using the method of Francis (2011) for weighting length data and the method of Punt (2017) for weighting age data. The CPUE series is balanced within Stock Synthesis, by estimating additional variance to each CPUE series, and improvements have been incorporated in the treatment of recruitment variance (σ_R) and 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 already reported (Day *et al.* 2020) for a preliminary base case with the same three-fleet model structure as the 2017 assessment. This full stepwise bridging was not repeated for the development of the five-fleet model, but comparisons were produced to show the differences between the updated three-fleet model and the new five-fleet model.

2 Methods

2.1 The data and model inputs

2.1.1 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.

Unlike the 2017 assessment, *M* was unable to be estimated within the model, although subsequent likelihood profile analysis (Day *et al.* 2020) suggests that perhaps *M* should not have been estimated in the 2017 assessment. Previous work has suggested a range of values for the mortality parameter *M*, for school whiting ranging from 0.37 (Bax and Knuckey 2001), 0.5 (Klaer and Thomson 2006), and 0.9 (Cui *et al.* (2004), Punt *et al.* (2005)).

The base-case value for the steepness of the stock-recruitment relationship, *h*, is 0.75.

School Whiting become sexually mature when the fish are around two years of age (Smith and Wayte, 2004), estimated at a length of about 16 cm (Day 20017, Day, 2009). However, Gray *et al*. (2014a,b), suggest that 50% of individuals attain sexual maturity at approximately 13-15cm in northern New South Wales (Newcastle and Yamba). 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).

2.1.2 Fleets

Unlike the 2017 assessment, this assessment for School Whiting is based on five fleets. These include the same three fleets used in the 2017 assessment, namely two Danish seine fleets (with NSW and Victorian fleets treated separately), a single otter trawl fleet, plus an additional NSW trawl fleet and a prawn trawl fleet. Both additional fleets operate exclusively in NSW state waters. Time-invariant logistic selectivity is assumed for all five fleets.

1. Victorian Danish seine – Danish seine based around Lakes Entrance in eastern Victoria and Bass Strait and Eastern Tasmania (1947 – 2019). Length frequency data are available for this fleet from Victorian Fisheries in 1991 and from the Integrated Scientific Monitoring Program (ISMP) and port records in the years 1994-2019. This fleet largely comprises catches from Commonwealth registered Danish seine vessels, but also includes small catches from Victorian and Tasmanian Danish seine vessels.
2. Trawl – otter trawlers including both Commonwealth and state registered vessels operating in: eastern Victoria; Bass Strait; and south of the Barrenjoey line in NSW (1947 – 2019). Length frequency data are available for this fleet for two years from the

Sydney Fish Market, 1983 and 1988, and from 1993, 1994 and 2014-2016 from the NSW observer program and from ISMP and port records from 1998-2019.

3. NSW Danish seine – Danish seine fleet operating in state waters in NSW (1942 – 1986, 2010-2019). Length frequency data are available for this fleet from the Sydney Fish Market from 1982 -1989 and 2015-2018. This fleet was not operating when the 2009 assessment was conducted but has been active since 2010.
4. NSW trawl – fish trawlers operating only in NSW state waters (NSW Ocean Zones 4-6) north of the Barrenjoey line (1947 – 2019). Onboard length frequency data are available for this fleet for 1993, 1994 and 2014-2016 from the NSW observer program. In addition, there are port length frequency data from 1951, 1971 and 1974, from 1983-1989, 1999-2005 and 2015-2019.
5. Prawn trawl – prawn trawlers operating in NSW state waters in (NSW Ocean Zones 1-6) north of the Barrenjoey line (1947 – 2019). Onboard length frequency data are available for this fleet for 1990-1996 and 2005-2007 from the NSW observer program. In addition, there are port length frequency data from 1983-1989, 2002 and 2015-2019.

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.

2.1.3 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 (1995) 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 and used for School Whiting assessments up until 2009.

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.

In the 2017 School Whiting assessment (Day 2017), the total NSW state catch was allocated in the ratio of 97% to the otter trawl fleet and 3% to the NSW Danish seine fleet from 1957-1994, after adjustments to the NSW catch total were completed. From 1995 to 2009 all of the NSW state catch was assumed to be otter trawl. From 2010, the Danish seine component of the NSW state catch is known. However, this NSW Danish seine catch from 2010 onwards is not publicly available. The recent NSW Danish seine catch data were used in this assessment, but not displayed in the report for reasons of confidentiality.

This NSW catch data was extensively revised for this assessment, with data adjustments made to reported catch and effort data from NSW state waters before CPUE standardisations were conducted and before inclusion of catch data in this assessment, to assign historical mixed Eastern School Whiting and Stout Whiting catches to separate species and correct known species misreporting in northern NSW waters (Hall 2021). In addition, the NSW catch history was separated into Danish seine NSW fish trawl (referred to hereafter as “NSW trawl” for brevity) and NSW prawn trawl fleets. This involved revision of historical assumptions, especially relating to NSW Danish seine catches. The NSW state catch was previously split into NSW Danish seine catches and NSW trawl catches, with the NSW trawl fleet (and catches) combined with the Commonwealth trawl fleet. The NSW trawl catch data (and biological data) were further split north and south of the Barrenjoey line, with catch and biological data for the NSW trawl fleet south of Barrenjoey, combined with catch and biological data from the Commonwealth trawl fleet, given that many of the vessels in that region are dual registered vessels with fishing licences from both state and Commonwealth waters. Some historical catches could not be assigned to either the NSW fish trawl and prawn trawl fleets, and these catches were apportioned between these two fleets in the same ratio as the known catch for those fleets in each year. This resulted in considerable revision to the catch history and the inclusion of catches back to 1942 (Hall 2021). The catch history used in the 2017 assessment started in 1947.

Tasmanian state catches are available from 1995-2019 and all of this catch was assigned to the Victorian Danish seine fleet.

Commonwealth catches from 1985-2019 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 five fleets used in this assessment (Victorian Danish seine, otter trawl, NSW Danish seine, NSW trawl, prawn trawl) are shown in Figure 1, Table 1 and Table 2, with recent NSW Danish seine catches redacted, and with only the total catches listed in Table 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 2.

This catch history is slightly modified from the catch history presented at the October 2020 SERAG meeting (Day *et al.* 2020), with updates to the Tasmanian state catch, and corrections to the catch history used for the preliminary five-fleet model, presented at that meeting. Issues were discovered in both the NSW trawl data north and south of Barrenjoey and corrections were made to these data.

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.

The state catch is a significant proportion of the total catch for School Whiting (Figure 2). From 1986-1996 the state catch averaged just under 40% 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 over 60% of the total catch in this period. In the three-year period from 2014-2016, the Commonwealth catch increased and the state catch decreased, with the Commonwealth catch averaging just over 50% in this period. Since 2017, the state catch has again increased, averaging over 65% of the total catch in the period 2017-2019. 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 over 85% of the total state catches in the period 1986-2019. The Commonwealth catch starts in 1985 and the Victorian Danish seine fleet comprises over 85% of the Commonwealth catch since 1986. The total Commonwealth catch was less than the total state catch in the period 1997-2013 and from 2016-2019.

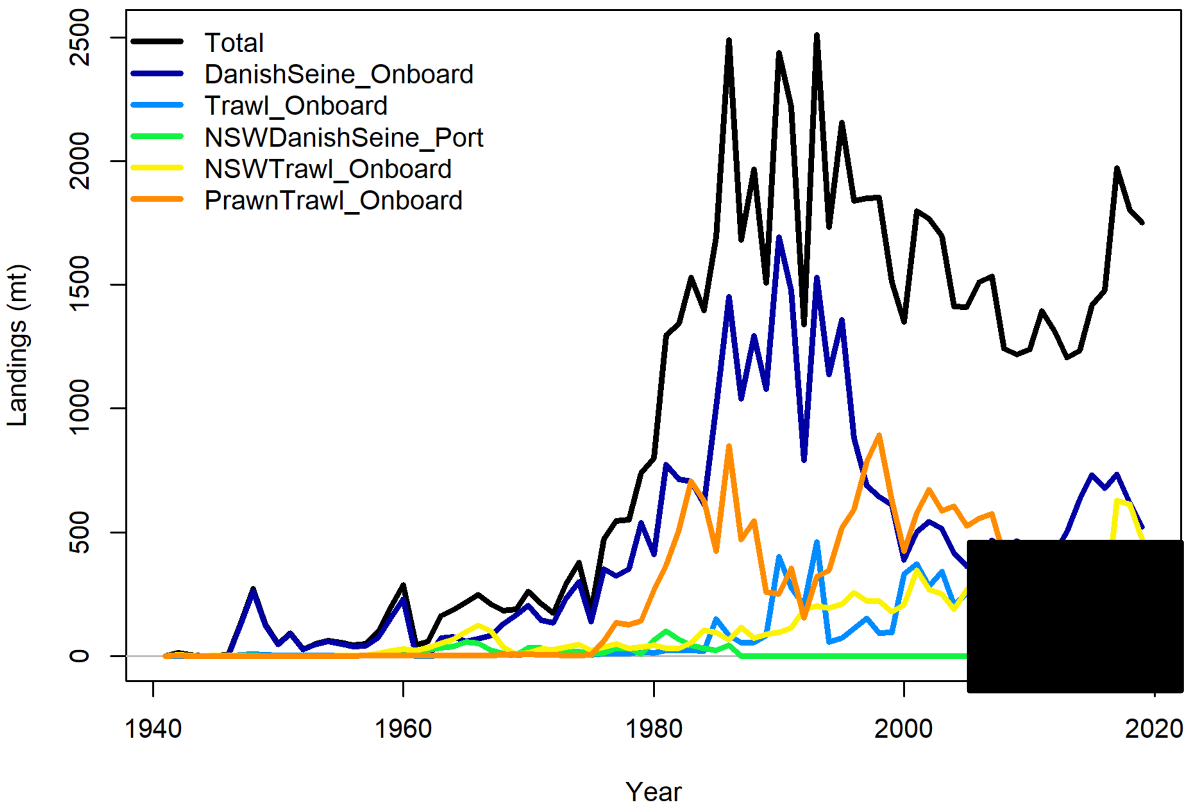


Figure 1. Total landed catch (tonnes) of School Whiting by fleet from 1942-2019. Recent NSW Danish seine catches are not publicly available.

In order to calculate the Recommended Biological Catch (RBC) for 2018, it is necessary to either estimate the calendar year catch for 2020, or to make an assumption about this catch. Without any other information, the 2020 catch for each fleet is assumed to be the same as the 2019 catch. The recent TAC history, which only applies to the Commonwealth component of the catch, is listed in Table 3 and plotted in Figure 2.

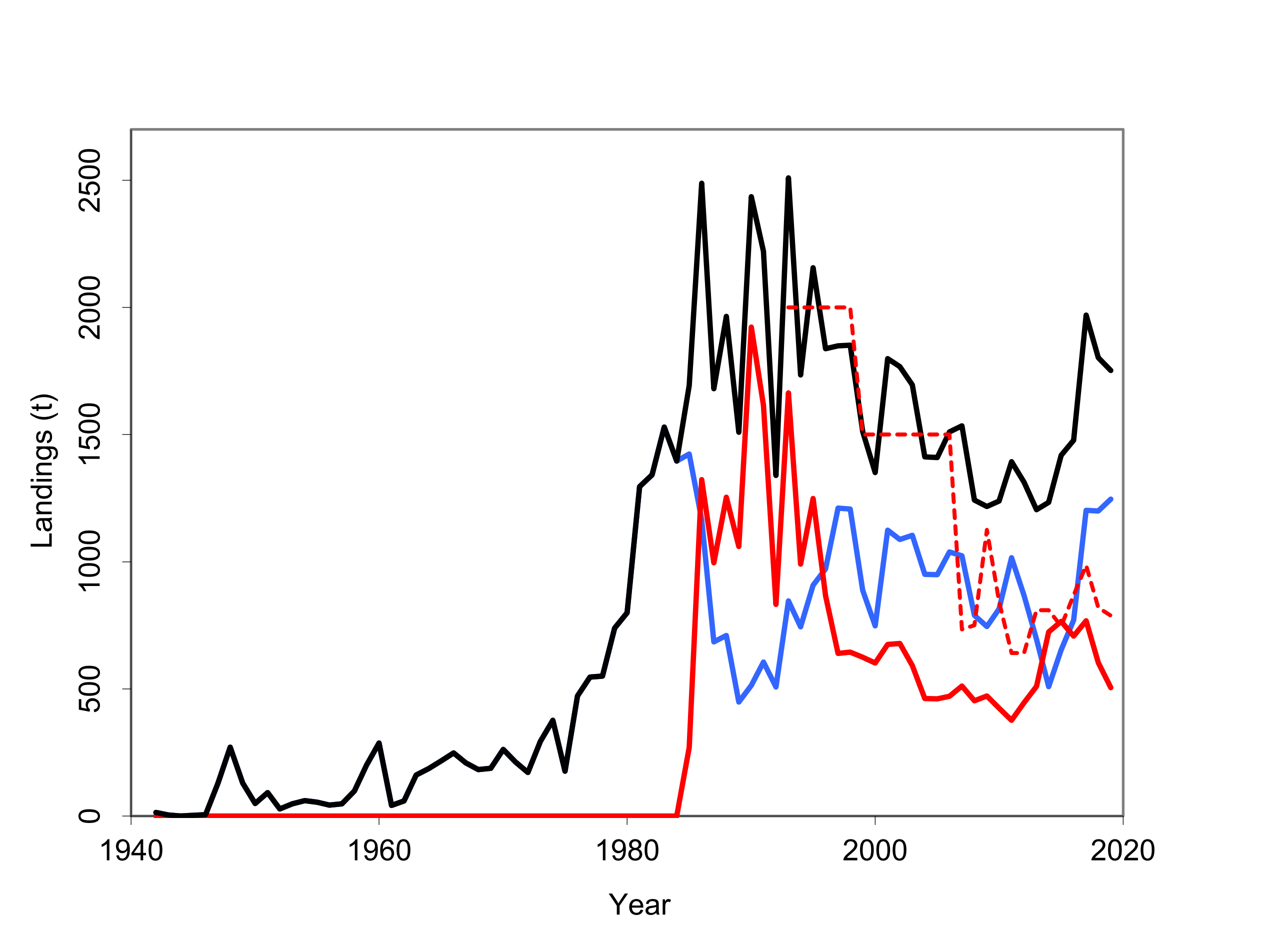


Figure 2. Total landed catch of School Whiting in the SESSF from 1942-2019 (black line) and this same catch separated into jurisdiction, with state catches (blue) and Commonwealth catches (red), and the Commonwealth TAC (red dashed line) from 1993-2019. The Commonwealth catch was larger than the state catch in the periods 1986-1995 and 2014-2015. The state catches (blue) comprise the whole catch until 1985. The Commonwealth catch starts in 1985.

Table 1. Total retained catches (tonnes) of School Whiting per fleet for calendar years from 1942-1980.

Year	DS	trawl	NSW DS	NSW trawl	prawn trawl	Total
1942	0	0	5	6	3	14
1943	0	0	1	3	0	4
1944	0	0	0	0	0	0
1945	0	0	1	1	0	3
1946	0	0	2	3	0	5
1947	122	4	2	1	0	129
1948	262	8	1	0	0	271
1949	125	4	0	0	0	129
1950	47	1	0	0	0	49
1951	89	3	0	0	0	92
1952	26	1	0	0	0	28
1953	46	1	0	0	0	48
1954	59	2	0	0	0	61
1955	49	2	0	2	0	54
1956	39	1	0	3	0	44
1957	41	1	2	2	2	48
1958	76	2	9	9	2	98
1959	154	5	19	21	2	200
1960	230	7	21	27	1	287
1961	0	0	19	23	1	42
1962	0	0	25	33	2	59
1963	73	2	34	50	3	162
1964	78	2	37	67	3	187
1965	59	2	56	98	2	217
1966	69	2	52	125	1	249
1967	81	3	23	100	3	210
1968	128	4	10	35	5	182
1969	164	5	5	6	7	187
1970	204	6	32	13	6	262
1971	143	4	33	28	4	213
1972	135	4	4	25	4	172
1973	233	7	15	37	1	293
1974	301	9	18	47	2	377
1975	139	4	6	23	4	177
1976	351	11	13	34	63	472
1977	322	10	32	49	134	546
1978	352	11	30	31	126	550
1979	538	17	6	35	142	739
1980	412	13	64	44	266	799

Table 2. Total retained catches (tonnes) of School Whiting per fleet for calendar years from 1981-2019. Only the combined total for all fleets is shown for 2010-2019.

Year	DS	trawl	NSW DS	NSW trawl	prawn trawl	Total
1981	772	24	101	30	368	1295
1982	714	22	67	31	509	1342
1983	705	22	44	55	705	1530
1984	614	20	31	103	627	1396
1985	1005	149	22	94	423	1693
1986	1451	81	44	65	848	2489
1987	1041	54	0	115	471	1680
1988	1293	54	0	73	545	1965
1989	1079	83	0	88	259	1509
1990	1691	400	0	94	251	2436
1991	1477	276	0	114	354	2221
1992	791	205	0	188	155	1339
1993	1529	461	0	201	319	2509
1994	1138	56	0	193	347	1734
1995	1359	71	0	210	516	2156
1996	880	110	0	257	591	1838
1997	688	152	0	222	787	1849
1998	645	94	0	222	891	1852
1999	610	95	0	179	627	1511
2000	388	330	0	207	425	1350
2001	502	372	0	345	579	1799
2002	544	282	0	270	671	1767
2003	515	342	0	251	588	1696
2004	415	206	0	188	604	1413
2005	362	253	0	270	525	1410
2006	393	268	0	293	556	1510
2007	469	220	0	272	573	1534
2008	427	228	0	185	403	1242
2009	464	153	0	295	305	1217
2010						1238
2011						1393
2012						1313
2013						1205
2014						1233
2015						1419
2016						1478
2017						1970
2018						1802
2019						1752

Table 3. Total allowable catch (TAC, tonnes) for School Whiting from 1993 to 2020.

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
2018	820
2019	788
2020	788

2.1.4 Discard rates

Information on the discard proportions of School Whiting by fleet is available from the ISMP for 1994-2019. This program was run by PIRVic from 1992-2006 and by AFMA from 2007. These data are summarised in Table 4. 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 4. Discard proportions for Vic Danish seine and otter trawl fleets from 1994 to 2019, with sample sizes for each data point (*n*), and NSW trawl and prawn trawl discard proportions from 1990-2019. 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 0.01).

Year	Vic DS discard proportion	*n*	Trawl discard proportion	*n*	NSW trawl discard proportion	Prawn trawl discard proportion
1990						0.357
1991						0.357
1992						0.357
1993					0.3200	
1994	0.0525	150	1	3	0.3200	
1995	0.0020	102	1	1	0.3200	
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	0.0564	34	0.0387	9		
2012	0.0278	17				
2013	0.0084	24	0.4664	6		
2014	0.0811	35	0.1187	4	0.2170	
2015	0.0311	51	0.2592	39	0.2170	
2016	0.0462	58	0.0580	6	0.2170	
2017	0.0142	44	0.1302	21		0.3210
2018	0.0212	46				0.3210
2019	0.1664	42	0.0528	8		0.3210

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 1%) are excluded as inputs to stock synthesis (the greyed figures in the proportion columns in Table 4) 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 4 – 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 3) and hence discarded catches for each fleet (Figure 4, Figure 5), with estimated discard rates of around 5% for the Danish seine fleet, around 10% for the trawl fleet, around 25% for the NSW trawl fleet and around 35% for the prawn trawl fleet (Figure 3).

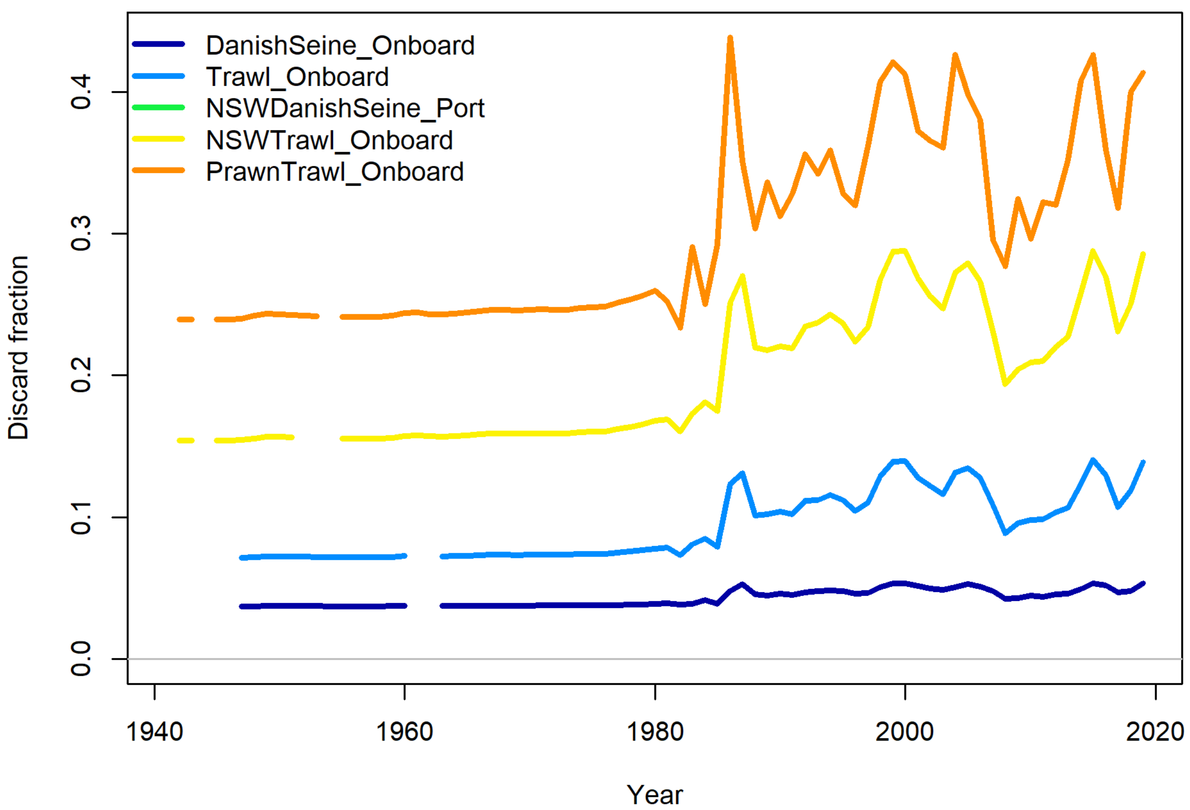


Figure 3. Model estimates of discard fractions by fleet, Danish seine (navy blue), otter trawl (royal blue), NSW trawl (yellow) and prawn trawl (orange).

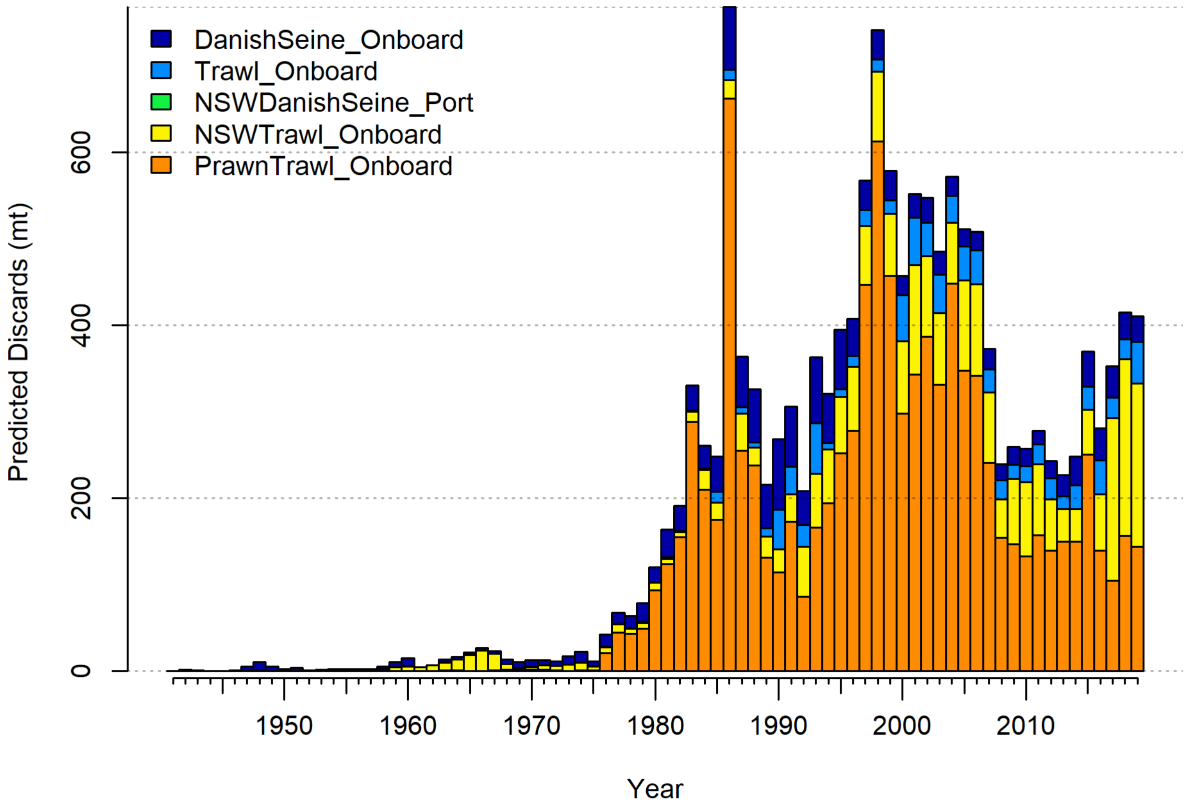


Figure 4. Estimated discards (tonnes, stacked) of School Whiting in the SESSF from 1947-2016, Danish seine (navy blue), otter trawl (royal blue), NSW trawl (yellow) and prawn trawl (orange).

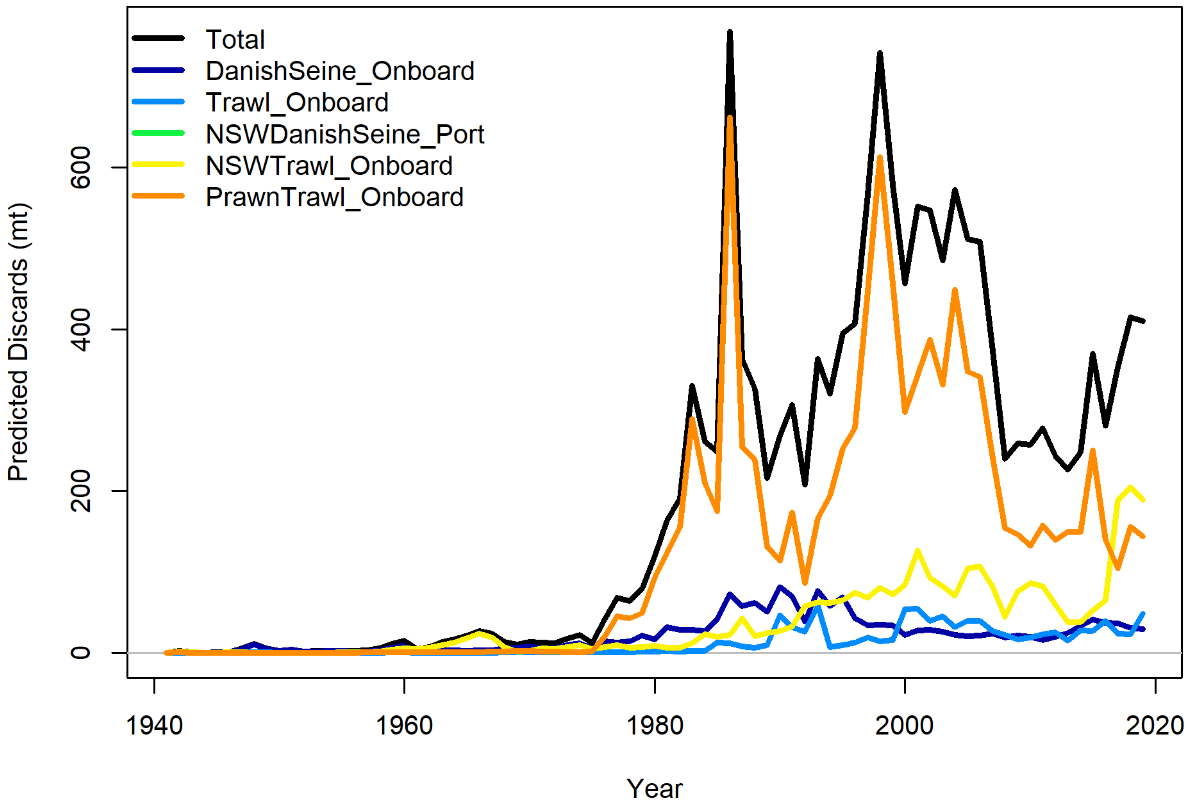


Figure 5. Estimated discards (tonnes) of School Whiting in the SESSF from 1947-2016, Danish seine (navy blue), otter trawl (royal blue), NSW trawl (yellow) and prawn trawl (orange).

2.1.5 Catch rate indices

Catch and effort data from the SEF1 logbook database were standardised using generalised linear models (GLMs) to obtain indices of relative abundance (Sporcic, 2020b; Table 5) from the period 1986-2019 for the Victorian Danish seine fleet and from 1995-2019 for the trawl fleet. Standardised CPUE series were also obtained using GLMs for the NSW trawl and prawn trawl fleets based on aggregated monthly (1998-2008) and aggregated daily (2010-2019) catch and effort data.

Table 5. Standardised CPUE indices and coefficient of variation for the Victorian Danish seine fleet and the trawl fleet for School Whiting (Sporcic, 2020b) and monthly and daily CPUE for the NSW trawl and prawn trawl fleets. The coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit for the Victorian Danish seine fleet and the trawl fleet (Sporcic, 2020a).

Year	CPUE Vic DS	cv (DS)	CPUE trawl	cv (TW)	monthly CPUE NSW TW	cv (NSW TW)	daily CPUE NSW TW	cv (NSW TW)	monthly CPUE prawn trawl	cv (prawn)	daily CPUE prawn trawl	daily CPUE (prawn)
1986	1.1675	0.182										
1987	1.2954	0.182										
1988	1.6522	0.182										
1989	1.0963	0.182										
1990	1.6932	0.182										
1991	1.4874	0.182										
1992	1.0845	0.182										
1993	1.5471	0.182										
1994	0.905	0.182										
1995	1.1487	0.182	1.2062	0.1770								
1996	0.7564	0.182	1.3472	0.1770								
1997	0.5706	0.182	0.9375	0.1770								
1998	0.5497	0.182	0.9478	0.1770	0.853	0.250			1.141	0.250		
1999	0.6311	0.182	1.1467	0.1770	0.684	0.250			0.936	0.250		
2000	0.6542	0.182	1.1482	0.1770	0.699	0.250			0.654	0.250		
2001	0.9021	0.182	1.2650	0.1770	1.080	0.250			0.815	0.250		
2002	0.8829	0.182	1.0503	0.1770	0.819	0.250			0.927	0.250		
2003	0.9247	0.182	0.9946	0.1770	1.235	0.250			0.628	0.250		
2004	0.8442	0.182	0.7684	0.1770	0.648	0.250			0.911	0.250		
2005	0.9403	0.182	1.0824	0.1770	0.978	0.250			1.039	0.250		
2006	0.8475	0.182	1.4923	0.1770	1.162	0.250			1.300	0.250		
2007	1.1221	0.182	1.4897	0.1770	1.375	0.250			1.215	0.250		
2008	1.1177	0.182	0.9502	0.1770	1.465	0.250			1.435	0.250		
2009	1.2075	0.182	0.8171	0.1770								
2010	1.0554	0.182	0.9785	0.1770			1.282	0.250			1.244	0.250
2011	0.8458	0.182	0.8424	0.1770			1.304	0.250			1.178	0.250
2012	0.9087	0.182	0.6214	0.1770			1.036	0.250			1.241	0.250
2013	0.9417	0.182	0.5533	0.1770			0.705	0.250			0.952	0.250
2014	1.0333	0.182	0.7539	0.1770			0.708	0.250			0.897	0.250
2015	1.0012	0.182	0.6872	0.1770			0.736	0.250			0.961	0.250
2016	0.9755	0.182	0.9409	0.1770			1.028	0.250			0.738	0.250
2017	0.9122	0.182	1.1389	0.1770			1.130	0.250			0.858	0.250
2018	0.6934	0.182	0.8062	0.1770			1.016	0.250			1.158	0.250
2019	0.6045	0.182	1.0338	0.1770			1.054	0.250			0.772	0.250

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.

2.1.6 Length composition data

Since 2017, both port and onboard retained length frequency data have been used in assessments. Assessments up until 2009 only used port data (Day, 2009). For the 2020 assessment, port and onboard length composition data are both used separately, with the gear selectivity for each fleet estimated jointly from both port and onboard data. For onboard data, the number of shots is considered 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 2020 assessment, the initial sample size for each length frequency used in the assessment is the number of shots or trips. This initial sample size is later modified through an iterative reweighting process.

Sample sizes for each fleet are listed for: discarded length frequencies, including both the number of individuals measured and number of shots, in Table 6 for the period 1994-2019; for whole catch (retained plus discarded) length frequencies, in Table 7 for the period 1990-2007; and for retained length frequencies in Table 8 and Table 9 for the period 1983-2019. Data from the NSW observer program is indicated in blue, the inferred numbers of trips (used in 1991 only) is listed in green, and shot numbers over 200 (which are capped at 200 for use in the assessment) are indicated in red. For 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 this gear type. 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 6, Table 8 and Table 9).

Length composition information for the retained component of the catch by the Victorian Danish seine fleet is available from port sampling for the period 1994-2019 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 eight years 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).

Table 6. Number of lengths and number of shots for discard length frequencies included in the base case assessment by fleet 1994-2019. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured). Entries in blue indicate data from the NSW observer program. Note that 2016 has a small sample (unused) from the ISMP (sample sizes in grey) and a larger sample (used) from NSW observer program (in blue), from south of the Barrenjoey line, (and hence part of the trawl fleet).

Year	Fleet	(discard)				
	Vic DS onboard	trawl onboard	NSW trawl onboard	Vic DS onboard	trawl onboard	NSW trawl onboard
	# fish	# fish	# fish	# shots	# shots	# shots
1994	8803			76		
1995	3900			39		
1998		160			2	
1999	292			8		
2001	160	253		4	9	
2002		81			2	
2003	13	532		1	7	
2004	86	155		1	3	
2005		205			2	
2009		14			2	
2010	1			1		
2011	5			2		
2012	95			5		
2014	202			13		
2015	46	178	768	3	5	24
2016	277	18 / 166	370	10	1 / 5	15
2017						
2018	272	365		5	7	
2019	561			15		

Table 7. Number of lengths and number of shots for whole (combination of retained plus discarded) length frequencies included in the base case assessment by fleet 1990-2007. Entries in blue indicate data from the NSW observer program, and entries in red are capped at 200 (maximum number of shots) when used in the assessment.

Year	Fleet	(whole)				
	trawl onboard	NSW trawl onboard	prawn trawl onboard	trawl onboard	NSW trawl onboard	prawn trawl onboard
	# fish	# fish	# fish	# shots	# shots	# shots
1990			4217			124
1991			5259			223
1992			1076			63
1993	1749	1454		92	70	
1994	1998	1891		108	68	
1995			9024			329
1996			2475			101
2005			166			6
2006			3656			52
2007			6776			86

Length composition information for the retained component of the catch by the trawl fleet is available from port and onboard sampling for 1998-2019 and in 1983 and 1988 from NSW state otter trawl sampled in port (Kevin Rowling, pers. comm. 2006) and the NSW observer program sampled onboard in 1993-1994 and 2014-2016, and sampled in port in 2017-2019. Length composition for the whole catch, comprising both retained and discarded fish, sampled prior to discarding, is available from the NSW observer program in 1993 and 1994. Onboard data collected by the ISMP were used to calculate the length frequency of the discarded component of the trawl catch for seven years from 1998-2019. An additional year of discard length frequency data came from the NSW observer program for the trawl fleet (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 1982-1989 and from port-based NSW observer measurements from 2015, 2016 and 2018 and from onboard-based NSW observers in 2015. Discarding for the NSW Danish seine fleet is thought to be very small and is assumed to be non-existent in this assessment. Discard information is not available for this fleet, neither in yearly estimated discard rates, nor yearly discard length frequency distributions.

Length composition information for the retained component of the catch by the NSW trawl fleet is available from early port sampling in 1951, 1971 and 1974, from 1983-1989, then periodically from 1999-2005 and more recently from 2015-2019. This is supplemented by onboard length frequency data collected by the NSW observer program from 2014-2016. Length composition for the whole catch, comprising both retained and discarded fish, sampled prior to discarding, is available from the NSW observer program in 1993 and 1994. Onboard data collected by the ISMP were used to calculate the length frequency of the discarded component of the trawl catch for two years only, 2015 and 2016.

Length composition information for the retained component of the catch by the prawn trawl fleet is available from port sampling from 1983-1989, in 2002 and more recently from 2015-2019. There is onboard length frequency data collected for the whole catch, comprising both retained and discarded fish, sampled prior to discarding, for the prawn trawl fleet from 1990-1992, 1995-1996 and 2005-2007. No length frequency information is available separately for the discarded component of the prawn trawl catch.

Table 8. Samples sizes for port and onboard retained length frequencies included in the base case assessment by fleet 1983-2019. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured). Some years contain separate length frequencies from the ISMP (black) and NSW (blue) observer programs for the trawl fleet (south of Barrenjoey for NSW data). Samples from the NSW observer program are indicated in blue.

Year	Fleet	(retained)							
	Vic DS onboard # fish	Vic DS port # fish	trawl onboard # fish	trawl port # fish	NSW DS onboard # fish	NSW DS port # fish	NSW trawl onboard # fish	NSW trawl port # fish	prawn trawl port # fish
1951								564	
1971								275	
1974								2757	
1982						224			
1983				436		2790		1726	1637
1984						1275		1777	2108
1985						370			162
1986						2046		1454	700
1987						449		1553	475
1988				500		260		854	432
1989						220		516	474
1991		2026							
1993			1749						
1994		527	1998						
1995		3511							
1996		2390							
1997		4190							
1998	233	5152	52	250					
1999	861	877	153	2547				176	
2000	462	776	253	45				329	
2001	453	523	1018	6340					
2002	743	303	2553	1726				885	206
2003	1836	315	3191	1615				259	
2004	767	1147	2757	11019					
2005	2425	1003	2392	7609 / 571				134	
2006	1333		1127	16866					
2007	242	2558		1056					
2008	67	894	52						
2009	335	880	228	288					
2010	558	1179	481						
2011	1607	1222	231	435					
2012	379	1263	40	46					
2013	1488	1488	278	181					
2014	861	1704	280 / 527	708			146		
2015	1841	2776	1265 / 1057	1086	159	20	852	191	2095
2016	2157	2386	122 / 3380	94		165	543	40	1991
2017	1317	2587	566	90 / 245				605	832
2018	1552	2903	179	103 / 3198		865		4675	2084
2019	858	1719	71	255 / 3241				4172	1613

Table 9. Number of shots or trips for length frequencies included in the base case assessment by fleet 1951-2019. The number of trips from the 1991 Victorian Danish seine (Vic DS) length frequency distribution (in green) is inferred using an average number of fish measured per shot for that gear type from other years with these data available. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured). Some years contain separate length frequencies from the ISMP (black) and NSW (blue) observer programs for the trawl fleet (south of Barrenjoey for NSW data). Samples from the NSW observer program are indicated in blue.

Year	Fleet	(retained)							
	Vic DS onboard	Vic DS port	trawl onboard	trawl port	NSW DS onboard	NSW DS port	NSW trawl onboard	NSW trawl port	prawn trawl port
	# shots	# trips	# shots	# trips	# shots	# trips	# shots	# trips	# trips
1951								3	
1971								1	
1974								6	
1982						1			
1983				2		5		6	7
1984						5		7	11
1985						1			1
1986						9		7	5
1987						1		8	2
1988				2		1		3	2
1989						1		3	2
1991		23							
1993			92						
1994		2	108						
1995		43							
1996		23							
1997		46							
1998	3	58	1	2					
1999	14	10	3	18				3	
2000	7	10	3	1				1	
2001	10	7	16	48					
2002	8	4	23	13				12	2
2003	16	3	32	8				3	
2004	7	9	22	27					
2005	17	7	21	15 / 7				1	
2006	11		10	60					
2007	1	13		5					
2008	4	7	2						
2009	5	15	3	4					
2010	18	20	3						
2011	27	38	3	1					
2012	8	35	1	1					
2013	21	34	5	3					
2014	25	38	2 / 7	6			4		
2015	31	38	19 / 27	8	2	1	32	3	34
2016	34	34	2 / 47	1		3	21	1	33
2017	18	37	6	1 / 3				5	10
2018	22	35	4	1 / 42		8		64	18
2019	16	24	3	1 / 53				55	181

2.1.7 Age composition data

An estimate of the standard deviation of age-reading error from age data was calculated by Paul Burch (pers. comm., 2020) using data supplied by Kyne Krusic-Golub for the Commonwealth fleets and ageing data from NSW DAF for the NSW fleets, using a variant of the method of Richards *et al.* (1992) (Table 10).

Age-at-length measurements from the Commonwealth fleets, based on sectioned otoliths provided by Kyne Krusic-Golub of Fish Ageing Services Pty Ltd, are available for the years 1991-1996, 1998, 2000-2019 for the Victorian Danish seine fleet and for the years 2001-2004, 2006, 2009-2019 for the trawl fleet. Age-at-length measurements from the NSW fleets from sectioned otoliths are available for 2005-2007 and 2015-2016 for the prawn trawl fleet, and for 2015 and 2016 for each of the NSW Danish seine and NSW trawl fleets (Table 11).

The Victorian Danish seine age-at-length data from the year 2000 was excluded in the 2017 assessment. A transcription error in processing this data in the 2017 assessment has now been corrected so this year of data is now included in the 2020 assessment. The 2018 onboard trawl length data was excluded as it had a suspicious large spike in the last length category that indicates a probable error in the processing. If this error can be corrected, this year of data may be included in a future assessment.

Table 10. Standard deviation of age reading error (P Burch pers. comm. 2020).

Age	Comm sd	NSW sd
0.5	0.190385	0.500233
1.5	0.190385	0.500233
2.5	0.264961	0.478947
3.5	0.292396	0.451363
4.5	0.302489	0.415616
5.5	0.306201	0.369292
6.5	0.307567	0.30926
7.5	0.308070	0.231464
8.5	0.308255	0.130648
9.5	0.308323	1.91E-08

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. These implied distributions can be calculated from 1998-2019 for the Victorian Danish seine fleet and from 1994-2019 for the otter trawl fleet.

Table 11. Number of age-length otolith samples included in the base case assessment by fleet 1991-2019 (NSW data in blue).

Year	Fleet Vic DS	Trawl	NSW DS	NSW trawl	prawn trawl	Total
1991	100					100
1992	419					419
1993	309					309
1994	430					430
1995	296					296
1996	278					278
1998	416					416
2000	218					218
2001	253	101				354
2002	234	250				484
2003	282	41				323
2004	372	87				459
2005	390				123	513
2006	263	51			835	1149
2007	43				1360	1403
2008	533					533
2009	232	129				361
2010	564	50				614
2011	520	56				576
2012	438	113				551
2013	165	38				203
2014	646	134				780
2015	760	371	38	159	72	1400
2016	443	217	112	201	67	1040
2017	410	40				450
2018	282	233				515
2019	464	168				632

2.1.8 Input data summary

The data used in this assessment is summarised in Figure 6, indicating which years the various data types were available.

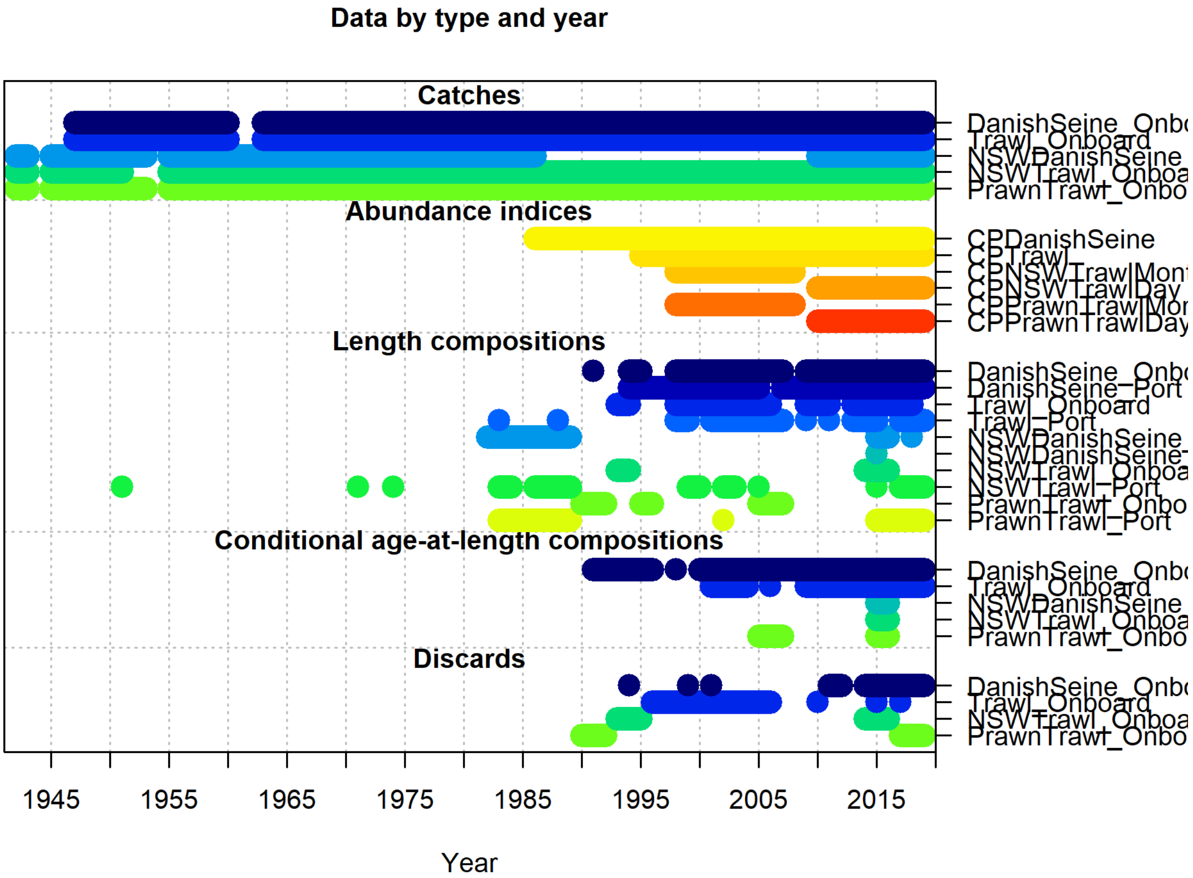


Figure 6. Summary of input data used for the School Whiting assessment.

2.2 Stock assessment method

2.2.1 Population dynamics model and parameter estimation

A single-sex stock assessment for School Whiting was conducted using the software package Stock Synthesis (version SS-V3.30.16.00, Methot *et al*. 2020). 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 1942. 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 (Sporcic, 2020a) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis. The CVs of the CPUE for the NSW trawl and prawn trawl fleets were initially set to 0.25 and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

(d) Five 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 four fleets where discard information was available (Victorian Danish seine, trawl, NSW trawl and prawn 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 fixed at 0.6 in this assessment, as it was unable to estimated.

(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 2016. Deviations are not estimated prior to 1981 or after 2016 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 0.7 in the base case. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

(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.

2.2.2 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 (Pacific Fishery Management Council, 2018). 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 (Francis 2011) for age and length composition data and the approach of Punt (2017) for conditional age-at-length 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 (2011) weighting method for length data and the Punt (2017) weighting method for conditional age-at-length data.

2.2.3 Iterative reweighting 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 SS-V3.30 there is an automatic adjustment made to survey CVs (CPUE). The iterative reweighting method is outlined below:

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). SS-V3.30 then re-balances the relative abundance variances appropriately.

2. The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_R, is set to 0.7, reflecting the variation in recruitment for School Whiting. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Methot and Taylor (2011).

An automated tuning procedure was used for the remaining adjustments. For the conditional age-at-length and length composition data:

3. Multiply the initial sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the 'Francis method' (Francis, 2011).
5. Repeat steps 3 and 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 (Pacific Fishery Management Council, 2018).

2.2.4 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 from 2006 onwards. 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 five 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 (2008a) 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.

2.2.5 Transition for three-fleet to five-fleet base case model, incorporating additional NSW data

At the October 2020 SERAG meeting, SERAG accepted an updated three-fleet assessment model, (Day *et al.* 2020), using the same model structure as used in the 2017 assessment (Day 2017). However, a preliminary alternative model structure, with two additional fleets, NSW trawl and prawn trawl, and a range of additional data sources from NSW was also presented. SERAG agreed to proceed with the alternative five-fleet model, noting that some additional work was required on: the preliminary catch series used for this five-fleet model; NSW conditional age-at-length data, which required additional processing and further scrutiny of the age adjustment field and treatment of multiple reads; a separate ageing error matrix for the NSW age data; and estimates of discarding rates for the NSW trawl and prawn trawl fleets. As long as these enhancements to the data and model could be incorporated in the model, SERAG agreed to proceed with the new model structure with five fleets, noting that this incorporates previously unused additional data from NSW on CPUE, length, age and discard rates. All data issues have subsequently been resolved with the modified data included in the new base case and included in the model presented here.

2.2.6 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.
2. h = 0.85.
3. M = 0.5 yr^{-1}
4. M = 0.75 yr^{-1}
5. 50% maturity at 14 cm.
6. 50% maturity at 18 cm.
7. σ_R set to 0.6.
8. σ_R set to 0.8.
9. Double the weighting on the length composition data.
10. Halve the weighting on the length composition data.
11. Double the weighting on the age-at-length data.
12. Reduce the weighting on the age-at-length data.
13. Increase the weighting on the survey (CPUE) data.
14. Halve the weighting on the survey (CPUE) data.
15. Exclude the Victorian Danish seine CPUE series.
16. Exclude the trawl seine CPUE series.
17. Exclude the NSW trawl CPUE series.
18. Exclude the prawn trawl CPUE series.
19. Exclude the Victorian Danish seine and the trawl CPUE series.
20. Exclude the NSW trawl and the prawn trawl CPUE series.
21. Include the Victorian Danish seine as the only CPUE series.
22. Include the trawl as the only CPUE series.
23. Include the NSW trawl as the only CPUE series.
24. Include the prawn trawl as the only CPUE series.
25. three-fleet model, using the same model structure as the 2017 assessment (Day 2017).

The results of the sensitivity tests are summarized by the following quantities (Table 15 and Table 18):

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2021}: the female spawning biomass at the start of 2021.

3. SSB_{2021}/SSB_0: the female spawning biomass stock status at the start of 2021.
4. Mortality: the model estimated value for mortality.
5. RBC_{2021}: the recommended biological catch (RBC) for 2021.
6. $RBC_{2021-23}$: the mean RBC over the three years from 2021-2023.
7. $RBC_{2011-25}$: the mean RBC over the five years from 2021-2025.
8. $RBC_{longterm}$: the longterm RBC.

The RBC values were calculated for the agreed base case only.

3 Results and discussion

3.1 Transition from 2009 base case to 2017 base case

3.1.1 Comparing the three-fleet model to five-fleet model

Development of a preliminary base case and a full bridging analysis from the 2017 assessment (Day 2009), was presented at the October 2020 SERAG meeting (Day *et al.* 2020), including updating the version of Stock Synthesis and sequentially updating data inputs to the model. This bridging analysis is not repeated in this report. A full step-by-step bridging from the three-fleet model to the five-fleet model is not informative due to the considerable structural changes in the model and the impact of iterative reweighting for the five-fleet model. However, a comparison between the tuned 2020 version of the three-fleet model (as presented at the October 2020 SERAG meeting) and the new fully tuned five-fleet base case model is presented below.

Figure 7 shows that the five-fleet model estimates a higher unfished spawning stock biomass than the three-fleet model (also shown in Figure 13). While the estimated population trajectory (Figure 7 and Figure 8) has similar general form, and results in a similar projection for 2021 stock status for the two models, the pathway is different in the two models, with the five-fleet model typically estimating lower stock status since 1980. However, the confidence intervals for the five-fleet model (shaded in red in Figure 8) are much narrower than those for the three-fleet model (shaded in blue in Figure 8).

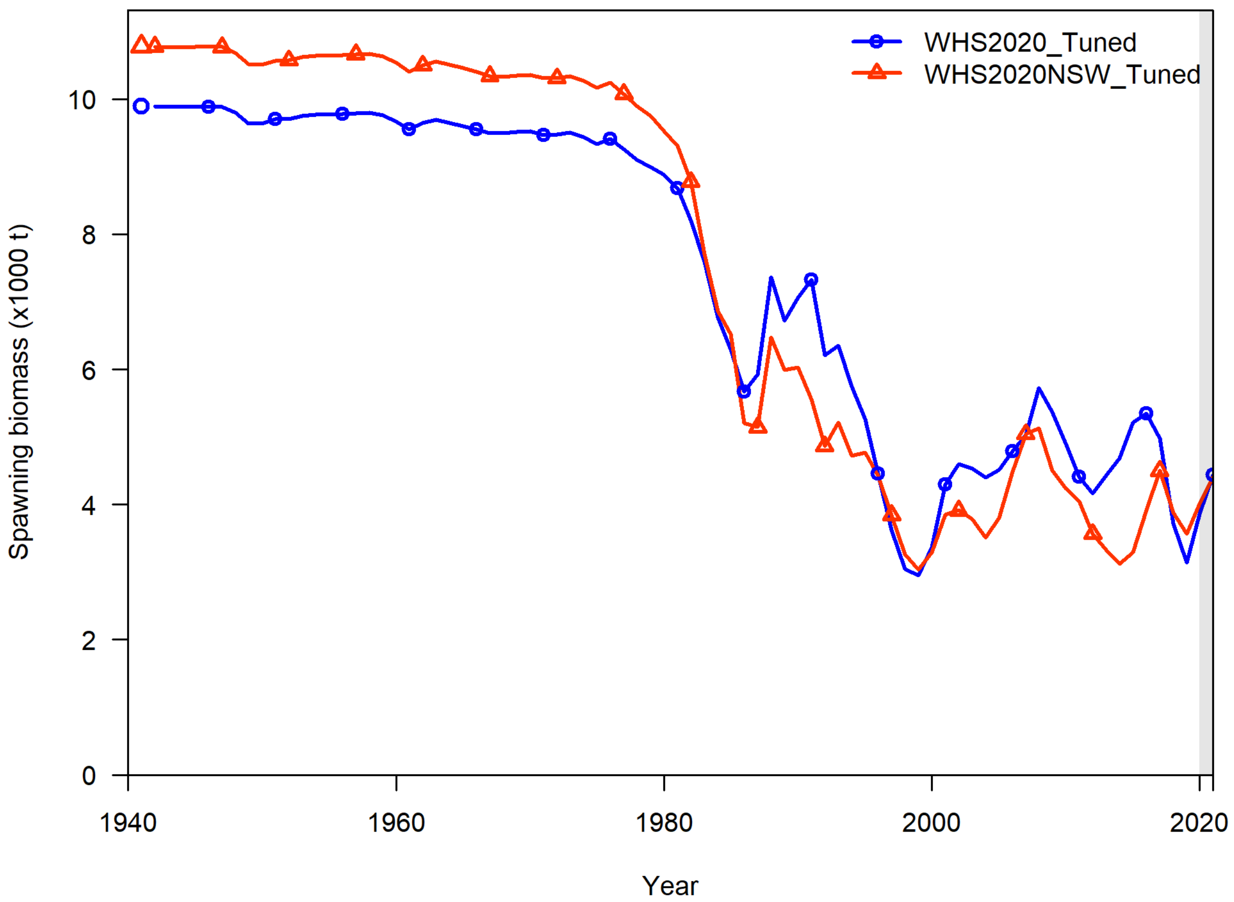


Figure 7. Comparison of the absolute spawning biomass time series for the three-fleet model, using updated data to 2020 (WHS2020_Tuned – in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red).

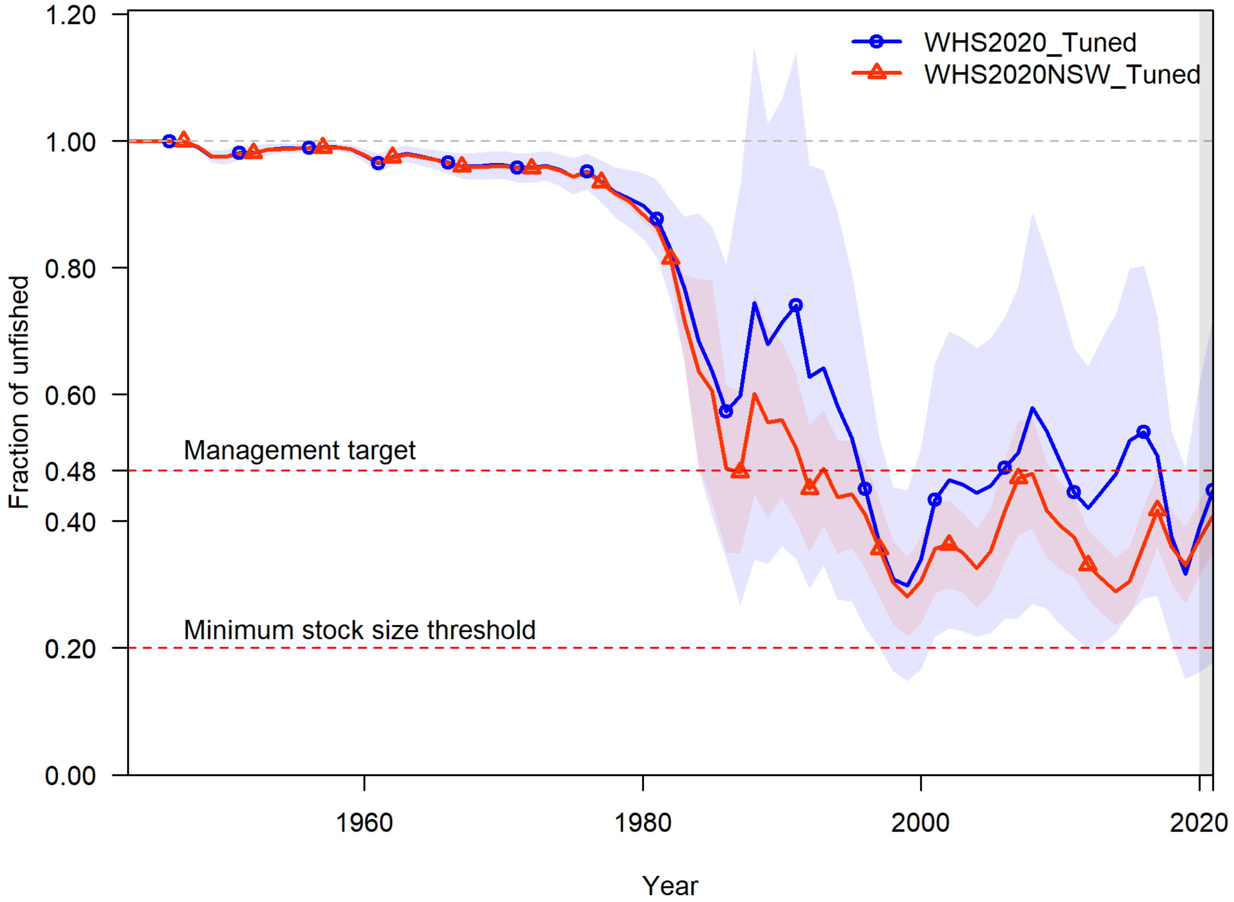


Figure 8. Comparison of the relative spawning biomass time series for the three-fleet model, using updated data to 2020 (WHS2020_Tuned in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red), with asymptotic confidence intervals shown in blue and red shading.

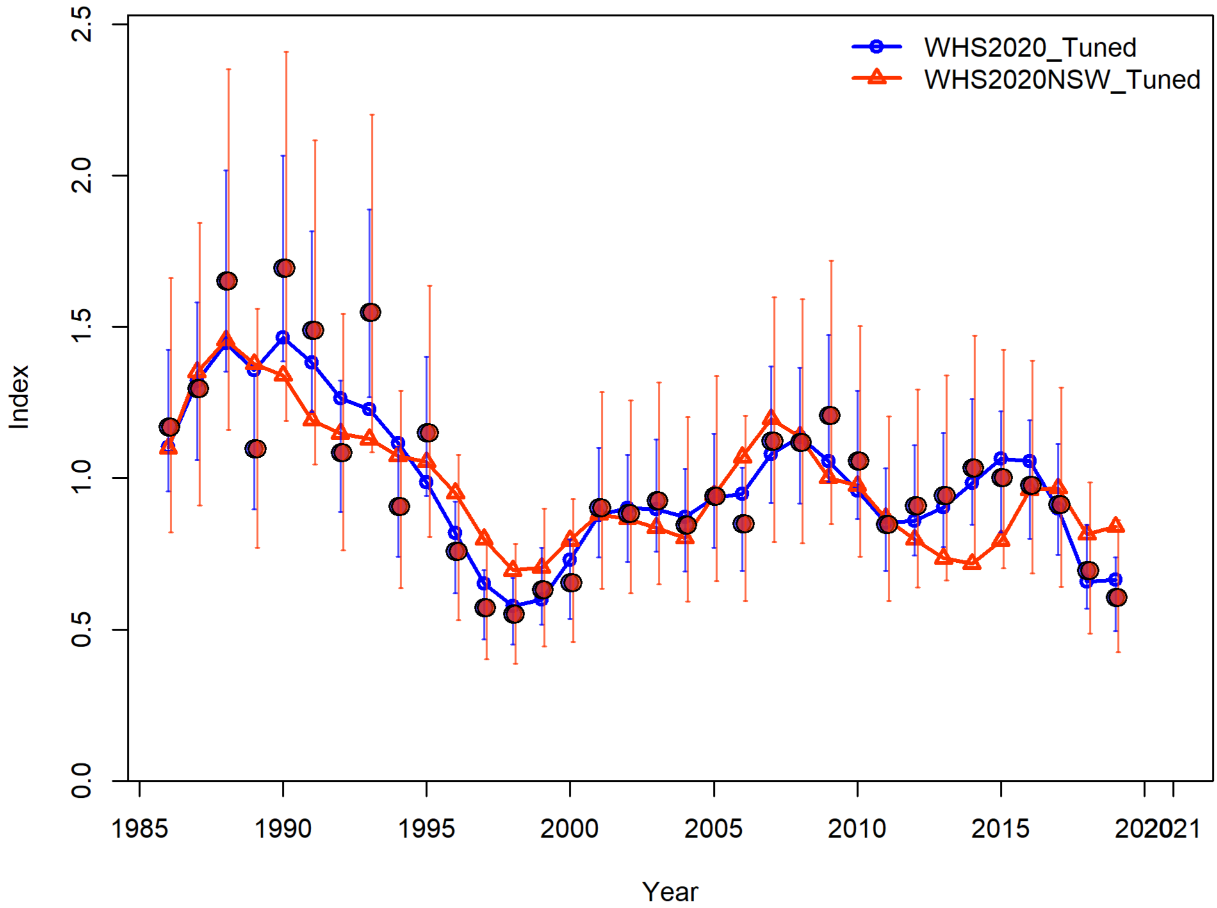


Figure 9. Comparison of the fit to the Victorian Danish seine CPUE index for the three-fleet model, using updated data to 2020 (WHS2020_Tuned in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red).

The fit to the Victorian Danish seine CPUE series (Figure 9) is better for the three-fleet model than the five-fleet model. This is not entirely surprising as there are four additional NSW CPUE series included in the five-fleet model, all of which appear to resemble the trawl fleet CPUE more closely than the Victorian Danish seine CPUE. The three-fleet model fits to the longer Victorian Danish seine CPUE series are much better than the fits to the trawl CPUE series. The addition of four additional CPUE series alters the balance of the data sources being fitted and, as a result, the fit to the trawl fleet is improved for the five-fleet model in comparison with the three-fleet model (Figure 10).

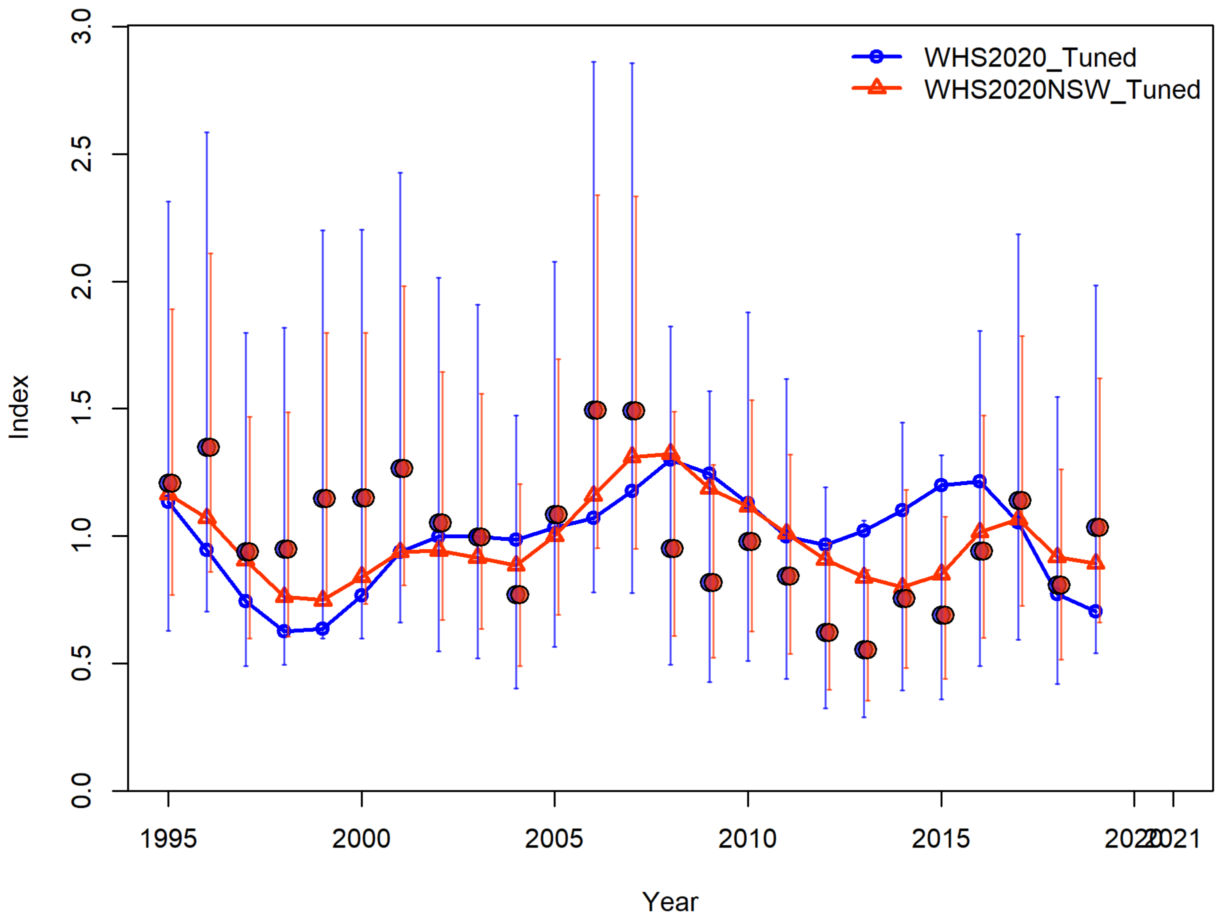


Figure 10. Comparison of the fit to the trawl CPUE index for the three-fleet model, using updated data to 2020 (WHS2020_Tuned in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red).

The pattern of recruitment is very similar for both models, as seen in the estimate of absolute recruitment numbers (Figure 11). Observing the patterns in the recruitment deviations (Figure 12), allows recruitment to be compared relative to baseline recruitment, and there are differences in these estimated deviations throughout the timeseries. These differences are more notable in the first four recruitment estimates, 1981-1984, (three revised up, one revised down) in 2004, (revised up), and in the last 10 estimates, from 2007-2016 (six revised up, four revised down). Importantly the 2016 recruitment deviation from the three-fleet model was the lowest recruitment deviation estimated in the whole series. While the 2016 recruitment deviation estimate from the five-fleet model is still below average, it is revised up considerably compared to the three-fleet model and is no longer the lowest recruitment deviation estimated in the series.

The differences in the estimated distributions of unfished spawning stock biomass is shown for the two models in Figure 13. Note that the absolute numbers of recruits estimated is different between the two models, in line with the different estimates for baseline recruitment (Figure 11) and the different estimates of unfished spawning stock biomass between the two models (Figure 13).

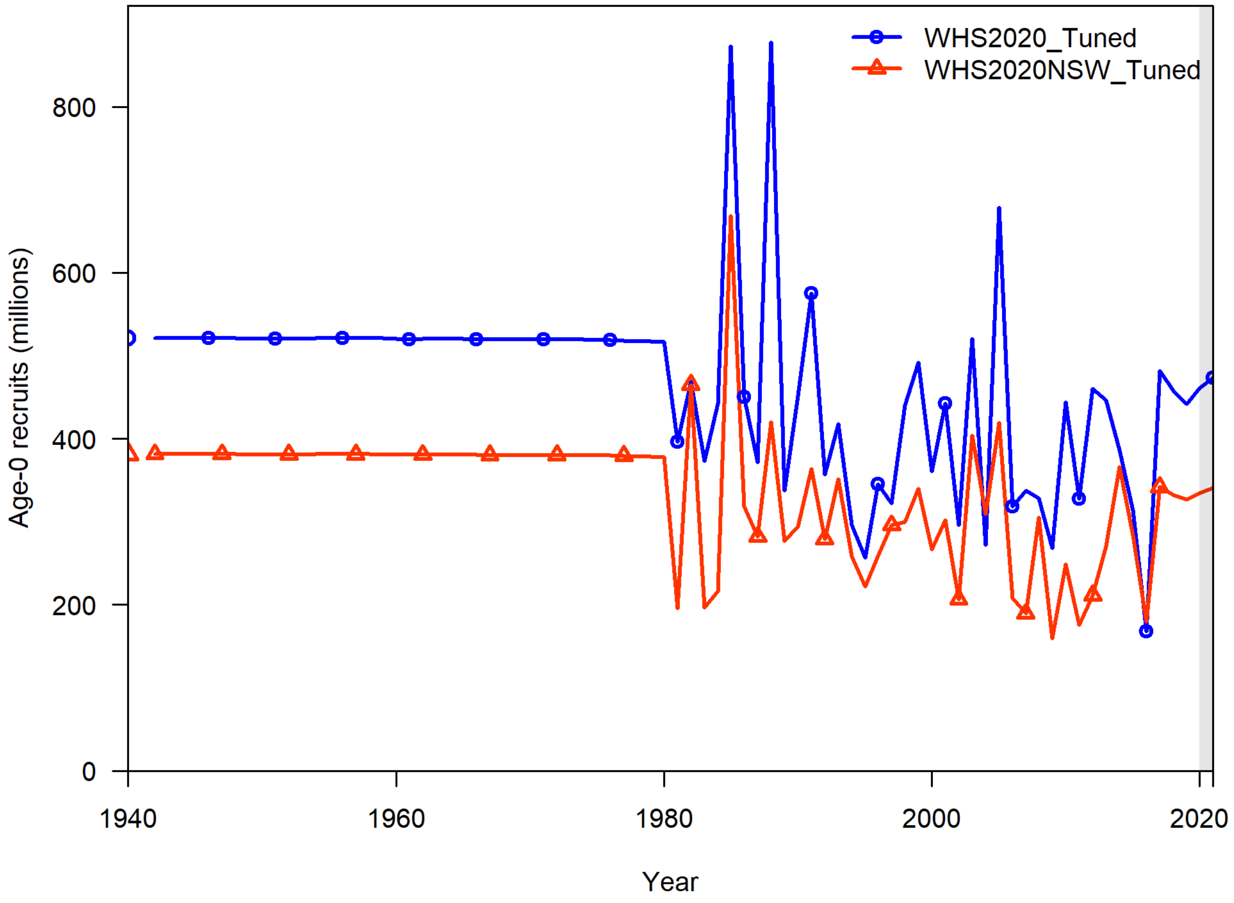


Figure 11. Comparison of the estimated recruitment time series for the three-fleet model, using updated data to 2020 (WHS2020_Tuned in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red).

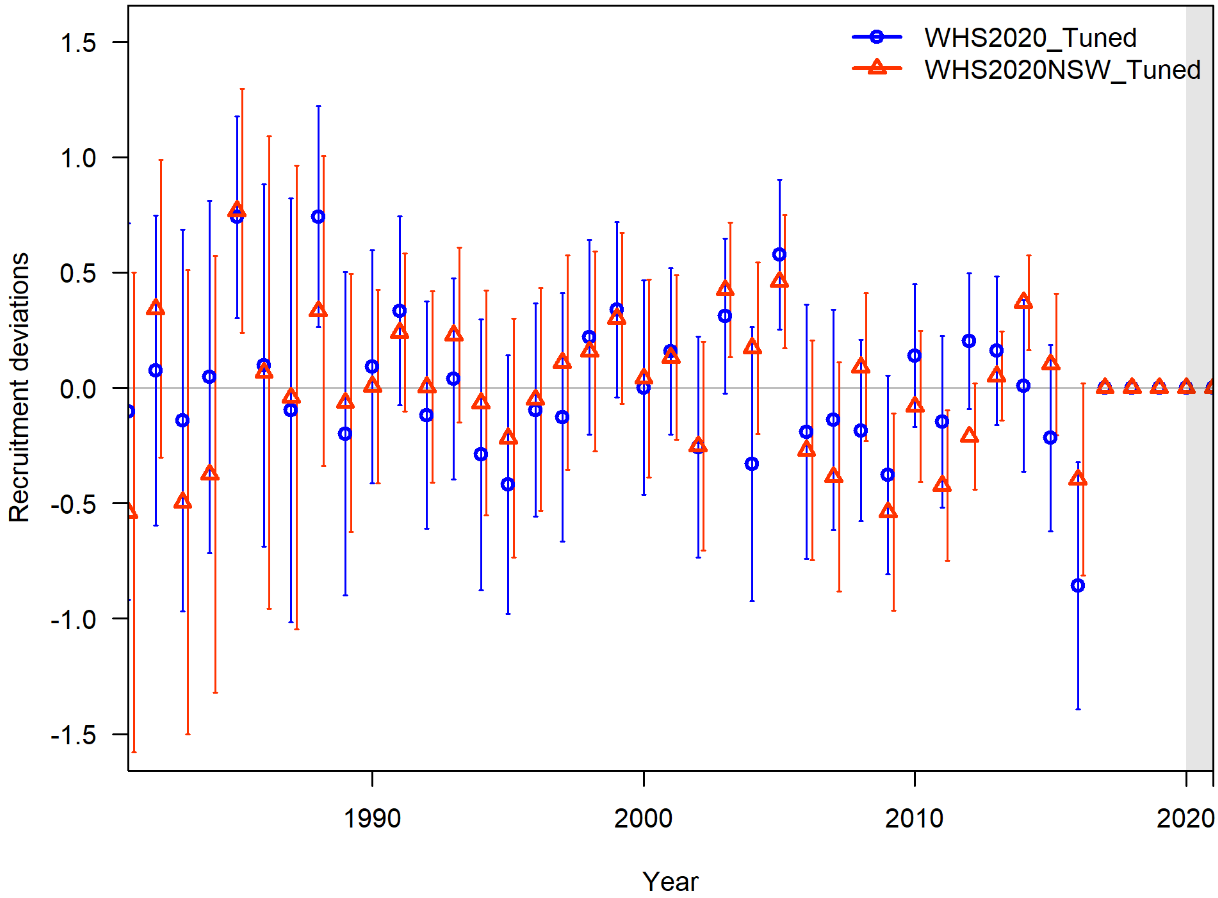


Figure 12. Comparison of the estimated recruitment deviations for the three-fleet model, using updated data to 2020 (WHS2020_Tuned in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red).

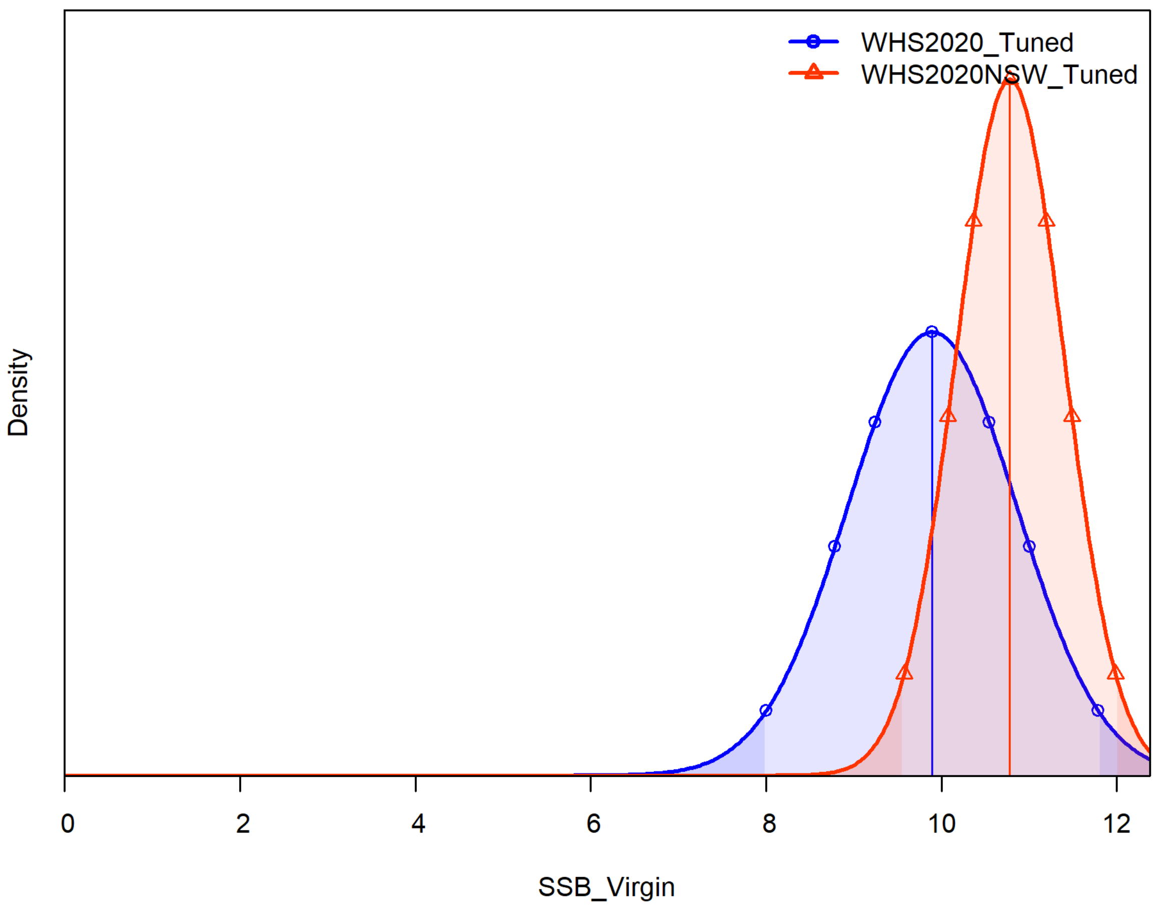


Figure 13. Comparison of the estimated unexploited spawning stock biomass for the three-fleet model, using updated data to 2020 (WHS2020_Tuned in blue) and the base case five-fleet model (WHS2020NSW_Tuned in red).

3.2 The base-case analysis

3.2.1 Parameter estimates

Figure 14 shows the estimated growth curve for School Whiting. All growth parameters are estimated by the model (parameter values are listed in Table 12).

Table 12. Summary of parameters of the base case model.

Feature	Details	
Natural mortality *M*	fixed	0.6
Steepness *h*	fixed	0.75
σ_R in	fixed	0.7
Recruitment devs	estimated	1981-2016, bias adjustment ramps 1969-1992 and 2015
CV growth	estimated	0.0937
Growth *K*	estimated	0.329
Growth l_{min}	estimated	7.26
Growth l_{max}	estimated	23.1

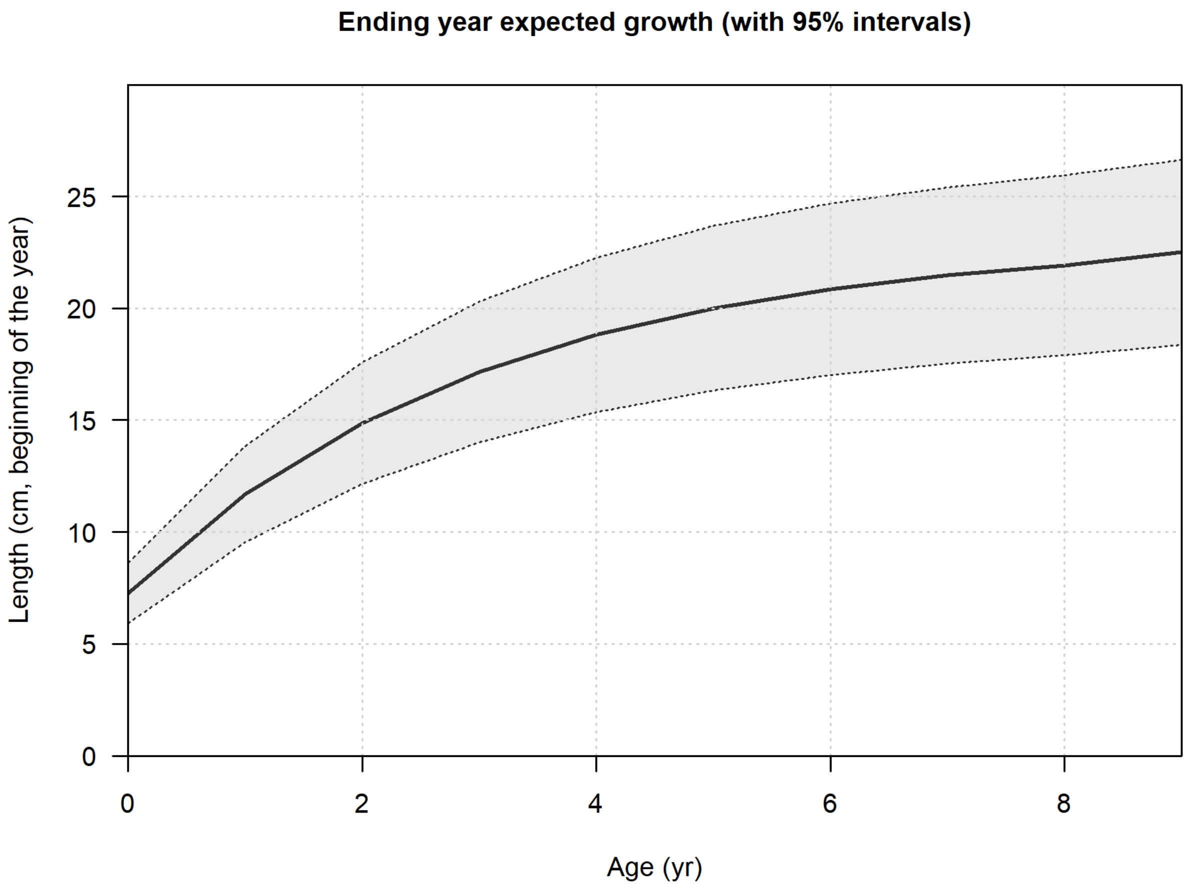


Figure 14. The model-estimated growth curve.

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 16.6 cm and 2.50 cm, for otter trawl are 18.2 cm and 4.13 cm, for NSW Danish seine are 16.4 cm and 2.79 cm, for NSW trawl are 19.0 cm and 5.66 cm and for the prawn trawl fleet are 14.7 cm and 7.36 cm. The selectivity for the NSWE Danish seine fleet is a little larger (around 2cm) than that estimated in the 2017 assessment, but the selectivity for the Victorian Danish seine and trawl fleets are similar to that estimated in 2017. Selectivity is estimated to be similar for the two Danish seine fleets (Victorian and NSW) and for the two trawl fleets (trawl and NSW trawl) (Figure 15). Selectivity estimates suggest that the prawn trawl fleet has the capacity to catch smaller fish than the other four fleets (Figure 15). Figure 15 shows the selectivity and retention functions for each fleet. Note that these fitted selectivities show that the trawl fleet tends to catch larger fish than other fleets (with NSW trawl fleet catching slightly larger fish than the trawl fleet), the two Danish seine fleets have very similar (intermediate) selectivity to each other (but catching smaller fish than the trawl fleets) and that the prawn trawl fleet catches smaller fish than all of the other fleets (Figure 15). 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 12.9 for the base case.

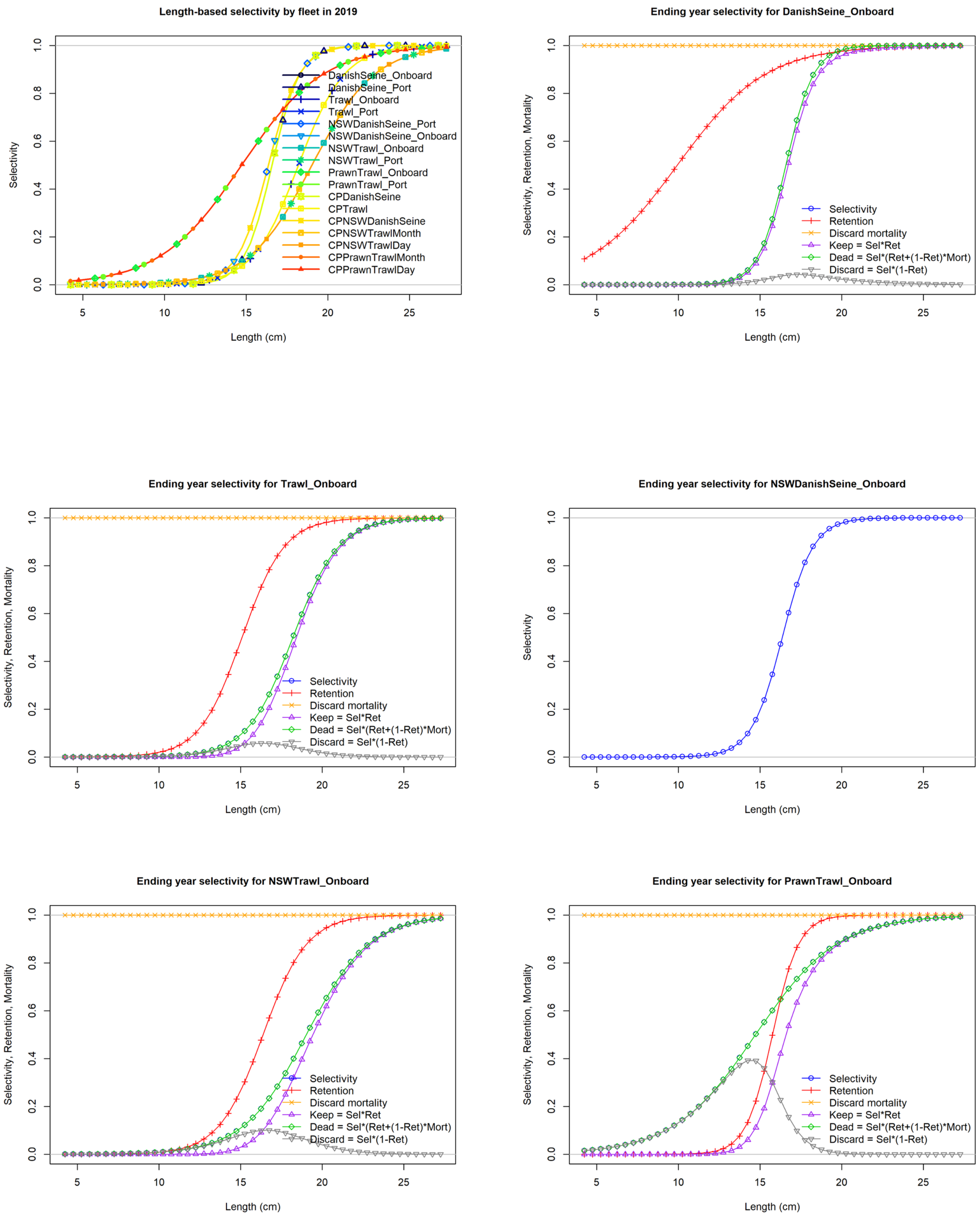


Figure 15. Selectivity for all five fleets (top left: Victorian Danish seine (lime green); trawl (yellow); NSW Danish seine (light orange); NSW trawl (dark orange); and prawn trawl (red)) and selectivity (blue/green) and retention (red) functions for the five fleets (Victorian Danish seine (top right); trawl (middle left); NSW Danish Seine (middle right); NSW trawl (bottom left); prawn trawl (bottom right)).

3.2.2 Fits to the data

The fits to the catch rate indices are generally good for the longest CPUE series, the Victorian Danish seine CPUE (Figure 16), especially up until 2011, with the worst fits to this CPUE series in the period from 2012-2019. The fits to the other five CPUE series (Figure 17, Figure 18 and Figure 19) are all acceptable, given the constraints of trying to fit multiple time series covering the same time period. The 2017 assessment produced excellent fits to the Victorian Danish seine fleet, but this assessment was only constrained by needing to fit two CPUE series simultaneously (Day 2017). The 2020 assessment has six different CPUE series, and four of these series cover the period from 2012-2019. The trends in the Victorian Danish seine CPUE series from 2012-2019 suggest two years of population increase followed by a monotonic decline through to 2019 (Figure 16). In contrast, the trends in the CPUE series for the trawl (general increase over the full period, Figure 17), daily NSW trawl (generally flat, but with an early dip, Figure 18) and daily prawn trawl (slow steady decline, Figure 19) fleets all show different patterns, and the model fits to all three of these CPUE series from 2012 to 2019 are generally better than the fit to the Victorian Danish seine series (Figure 16 - Figure 19).

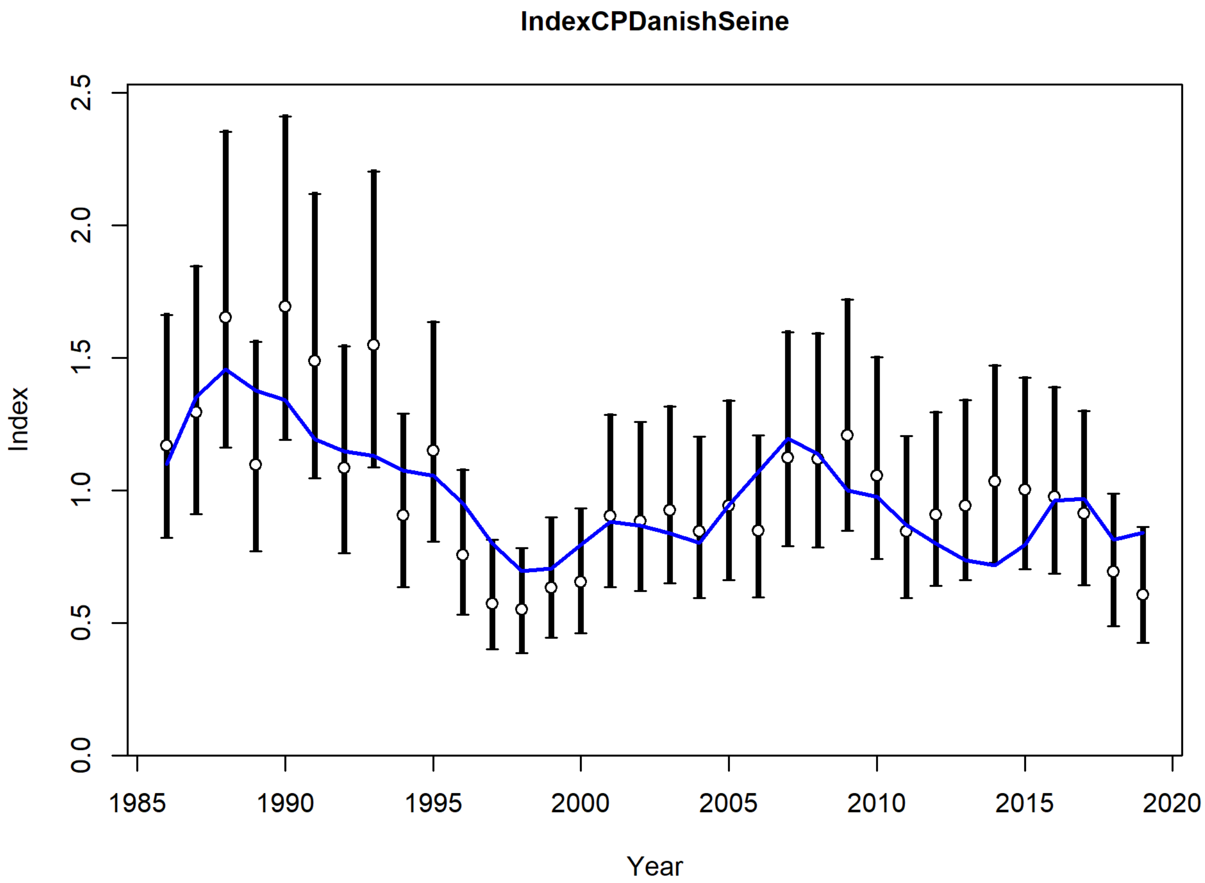


Figure 16. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% confidence intervals for Victorian Danish seine fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is (only just) negative, suggesting the model fits well with less variance than the initial values from the loess fit.

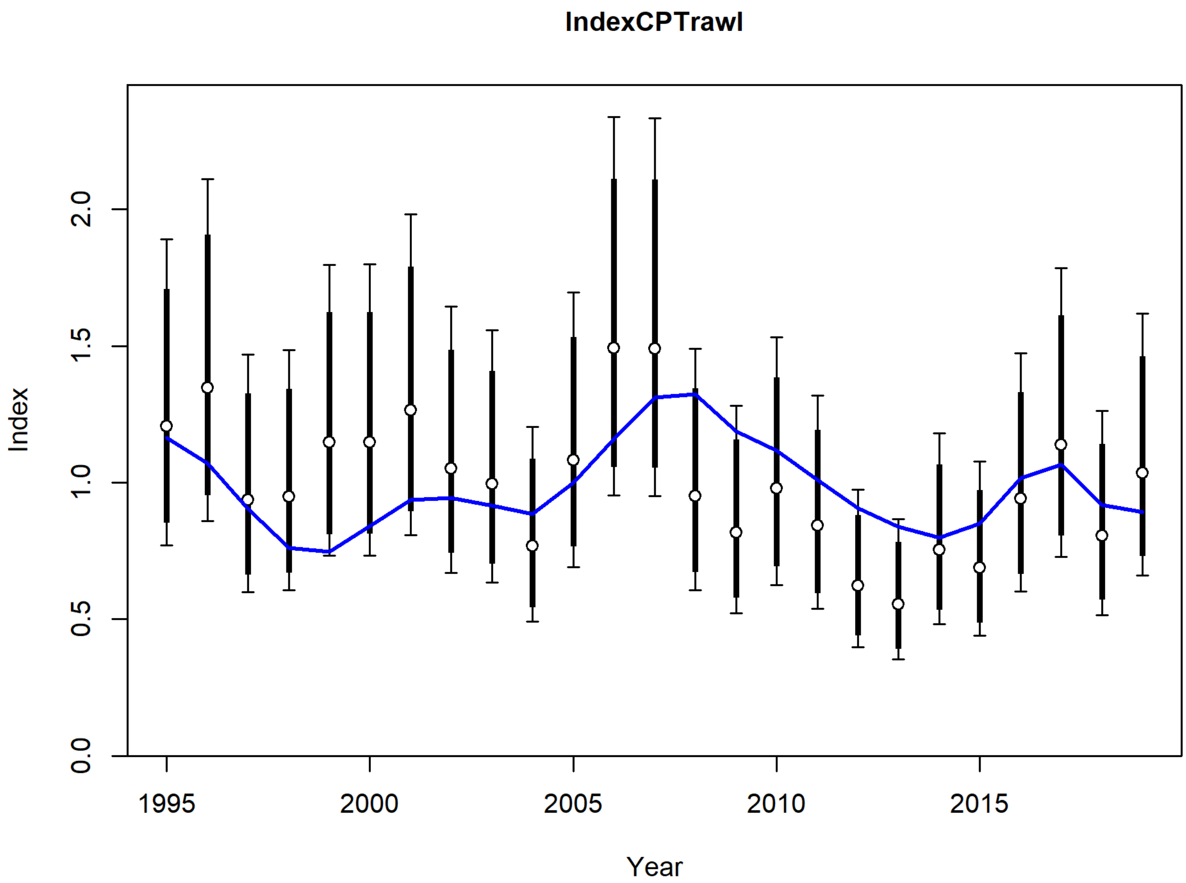
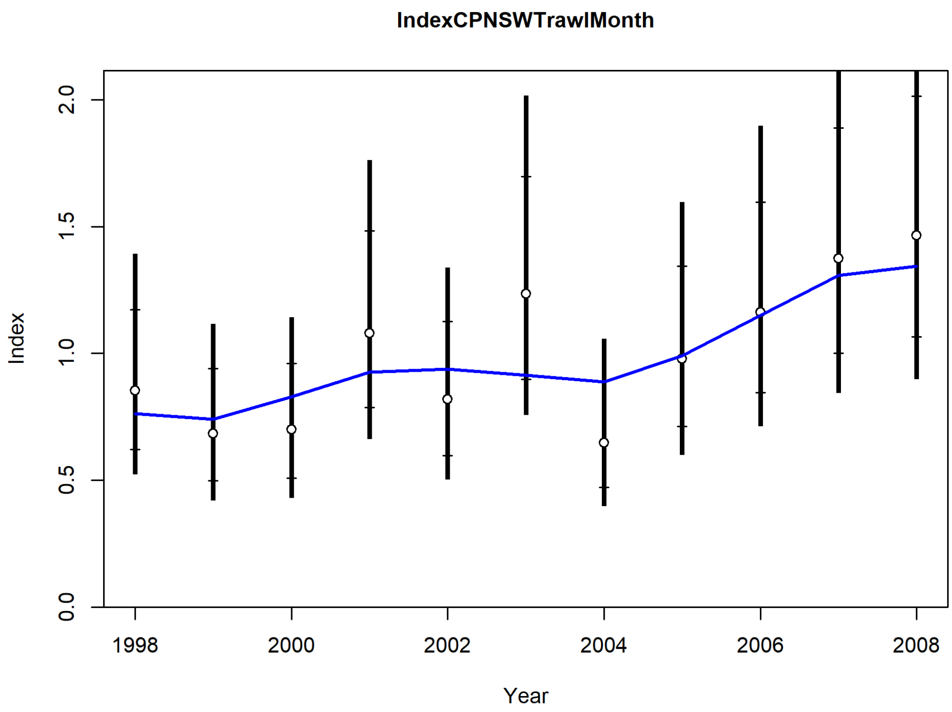


Figure 17. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% confidence intervals for otter trawl fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter 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 total standard error, comprising the input standard error (Table 5) plus the additional standard error estimated within Stock Synthesis, gives some measure of how well each CPUE series is fit. This total standard error is lowest for the NSW trawl fleet, 0.16 for the monthly series and 0.14 for the daily series, followed by the Victorian Danish seine at 0.18, the prawn trawl fleet with 0.21 for the monthly series and 0.22 for the daily series, and the trawl fleet with the largest value at 0.23. It is generally easier to fit shorter time series, and conflicting signals between multiple CPUE series also adds to the difficulty of fitting to CPUE. Overall, the fits to all of the CPUE series are remarkably good (as shown by the patterns in residual plots in Figure 20), especially the longest time series from the Victorian Danish seine CPUE which covers 33 years. The fit to the trawl series is improved in this assessment, compared to the fits obtained in the 2017 assessment, mostly due to the requirement to also fit the additional four NSW CPUE series.

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. All series showing a generally stable trend, albeit with some variation, since the late 1990s through until 2019 (Figure 16 - Figure 19).



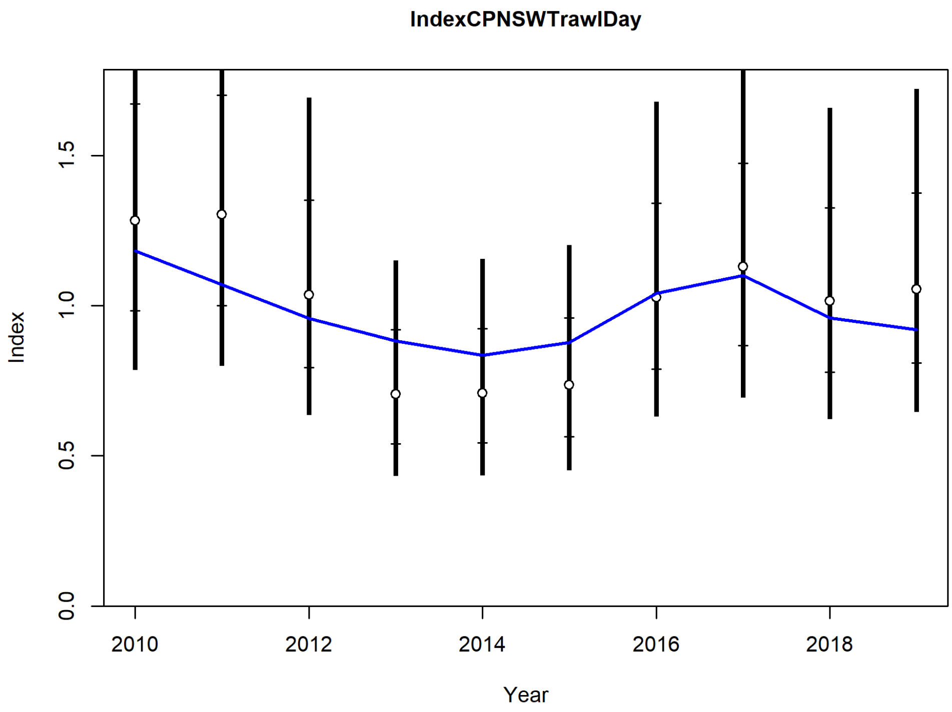
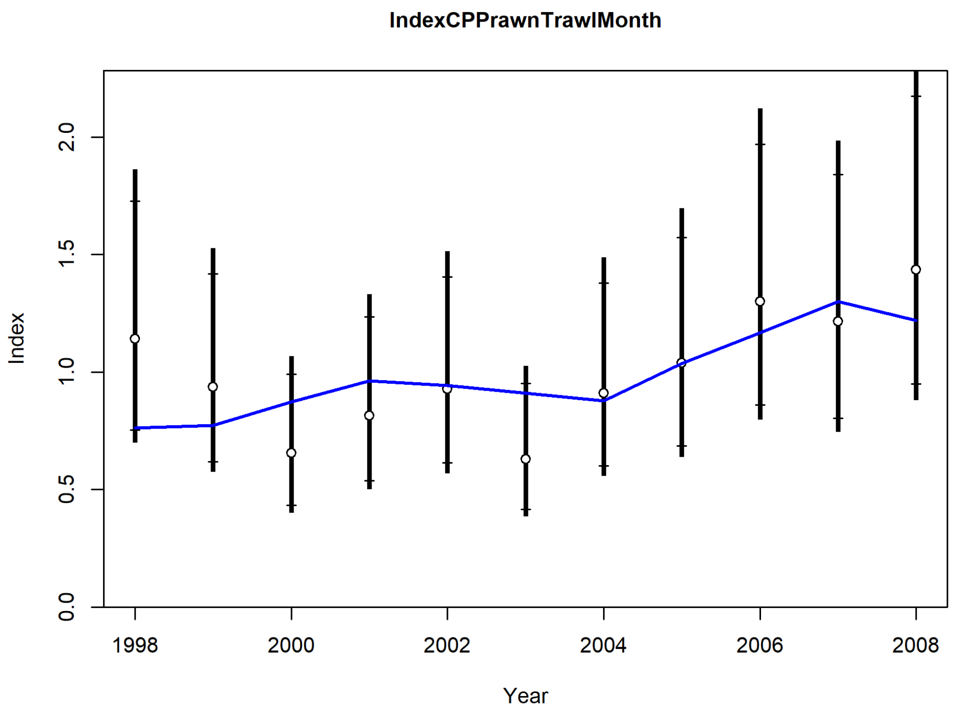


Figure 18. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% confidence intervals for NSW trawl fleet, separated into two series - monthly (upper) and daily (lower). The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model requires less variance than the initial values chosen (0.25) to achieve a good fit.



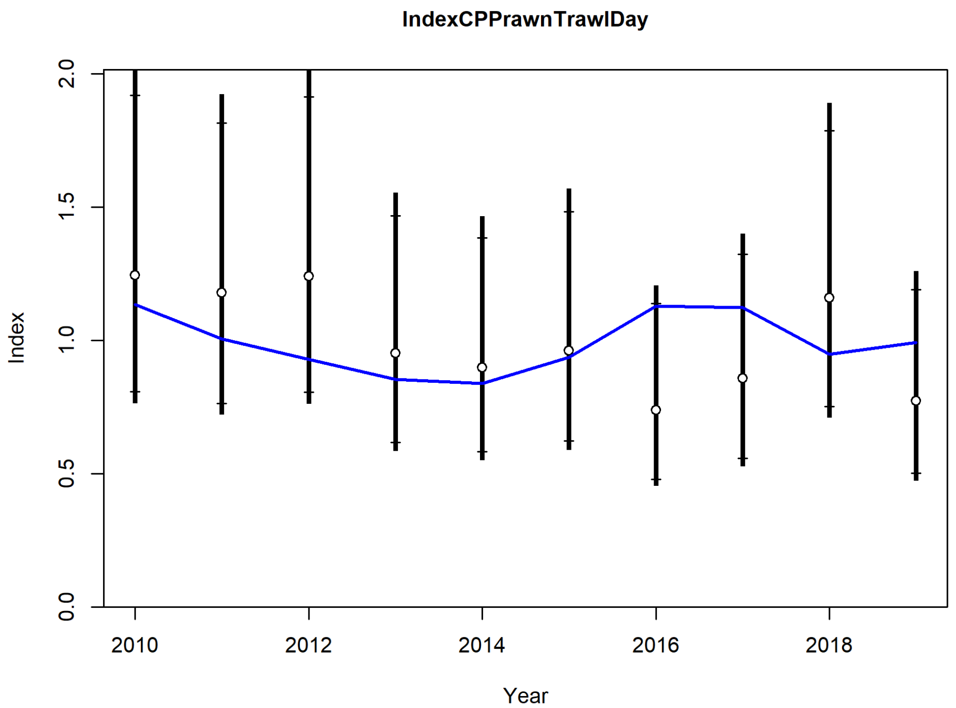


Figure 19. Observed (circles) and model-estimated (blue line) catch rates vs year, with approximate 95% confidence intervals for the prawn trawl fleet, separated into two series - monthly (upper) and daily (lower). The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model requires less variance than the initial values chosen (0.25) to achieve a good fit.

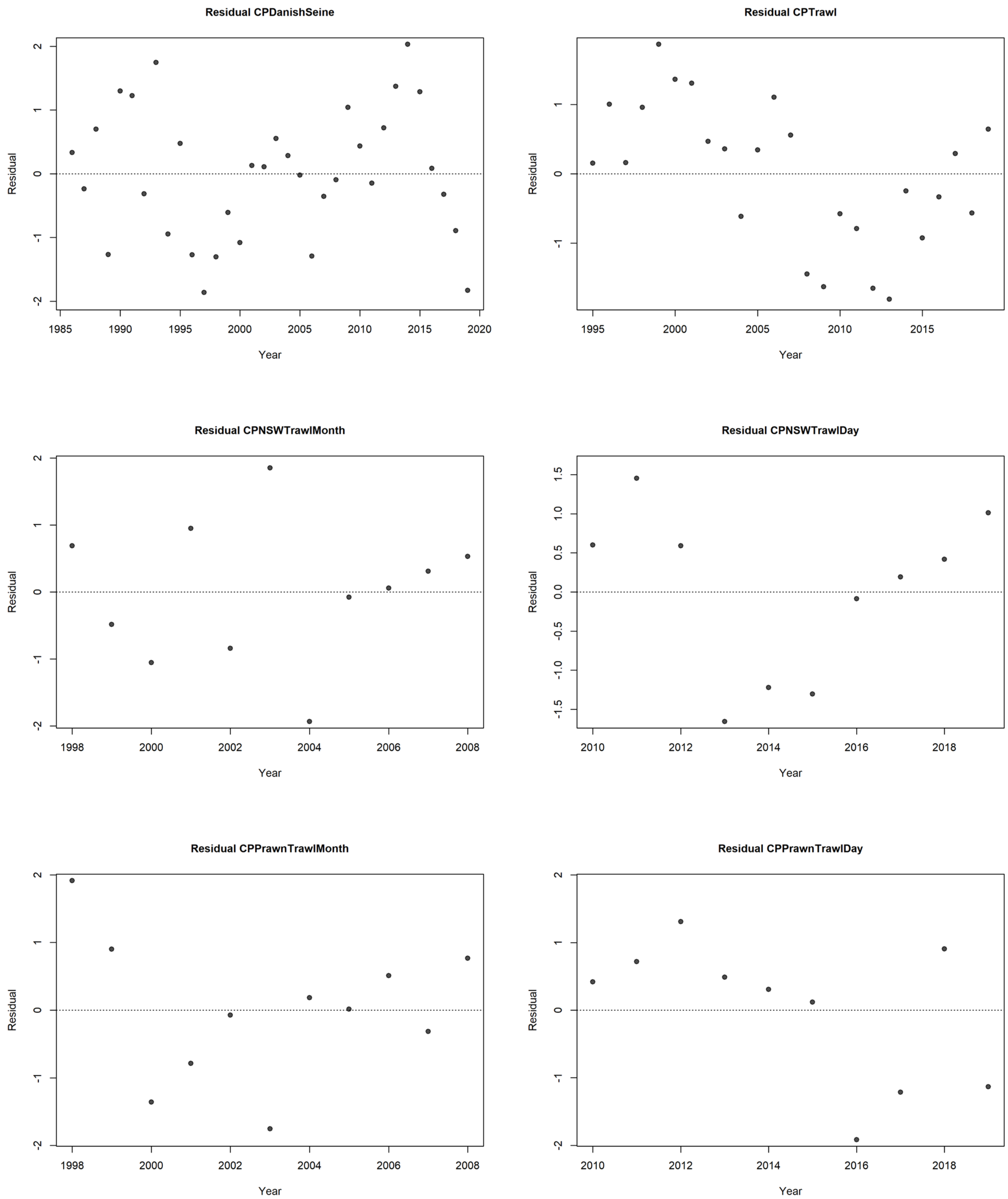


Figure 20. Residual patterns for fits to the six CPUE series: Victorian Danish seine (top left); trawl (top right); monthly NSW trawl (middle left); daily NSW trawl (middle right); monthly prawn trawl (bottom left); daily prawn trawl (bottom right).

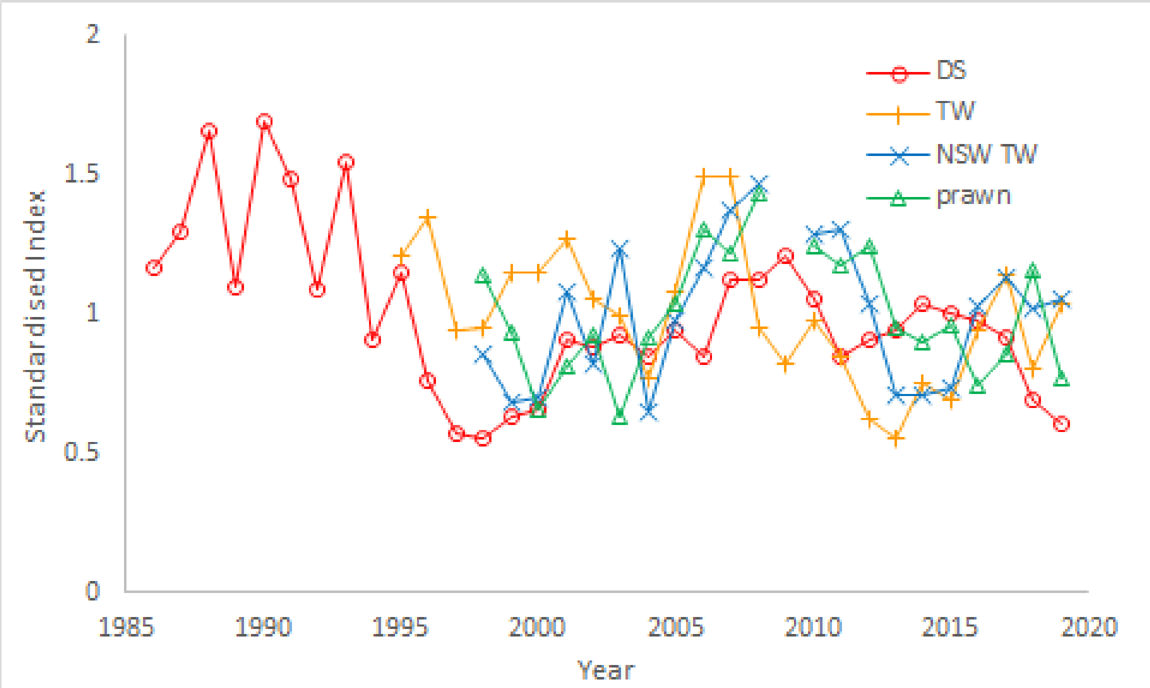


Figure 21. All six CPUE series plotted on a normalised scale (mean of each series equals 1), enabling comparison of trends between time series.

The fits to the discard rate data (Figure 22 and Figure 23) are reasonable for all fleets. 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 4). 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, eight years of discard data for the trawl fleet were excluded (1994, 1995, 2007, 2011, 2013, 2014, 2016 and 2019, with discard rates varying between 4% and 100%, Table 4) as these data come from sample sizes of less than ten, resulting in 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.

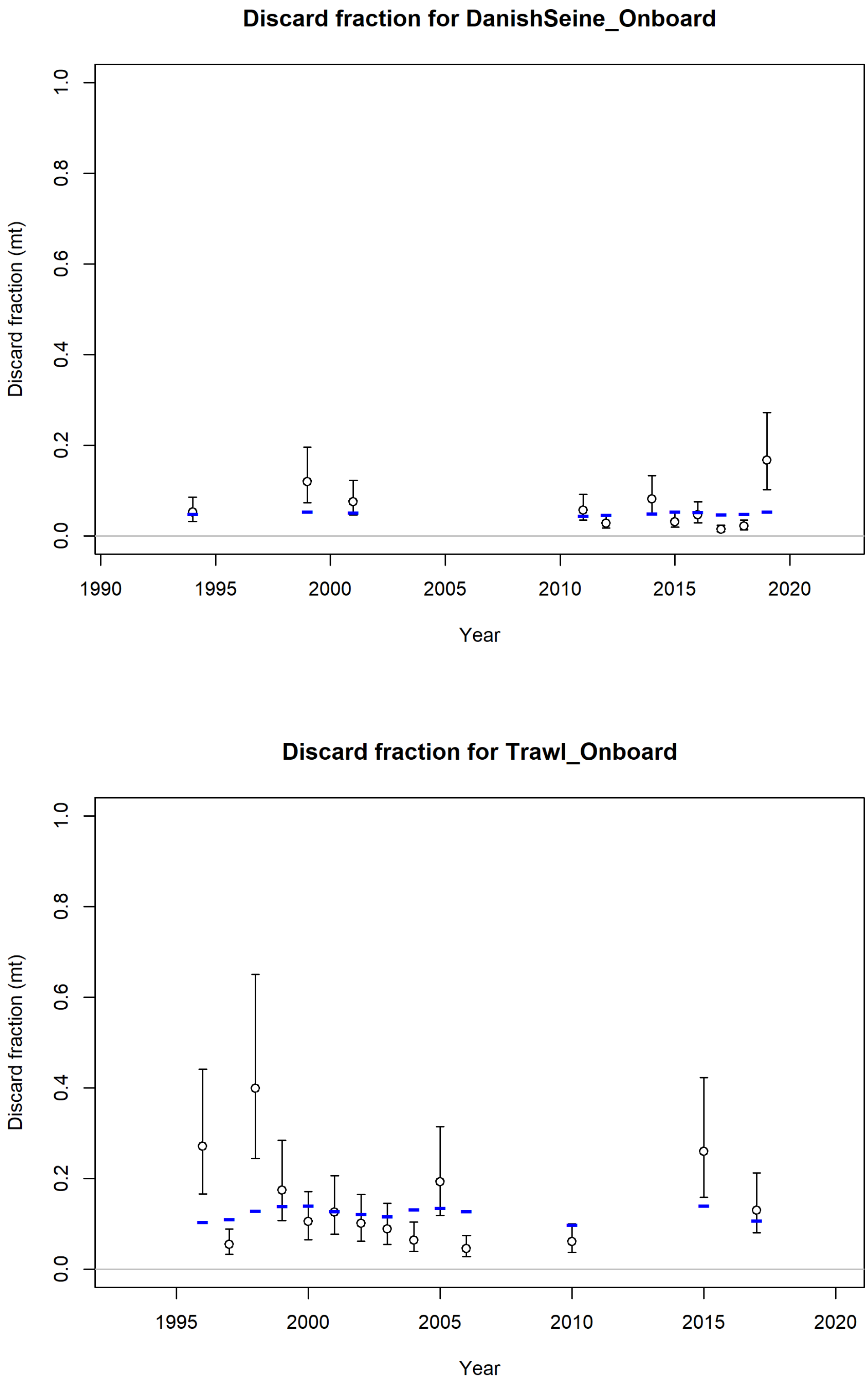
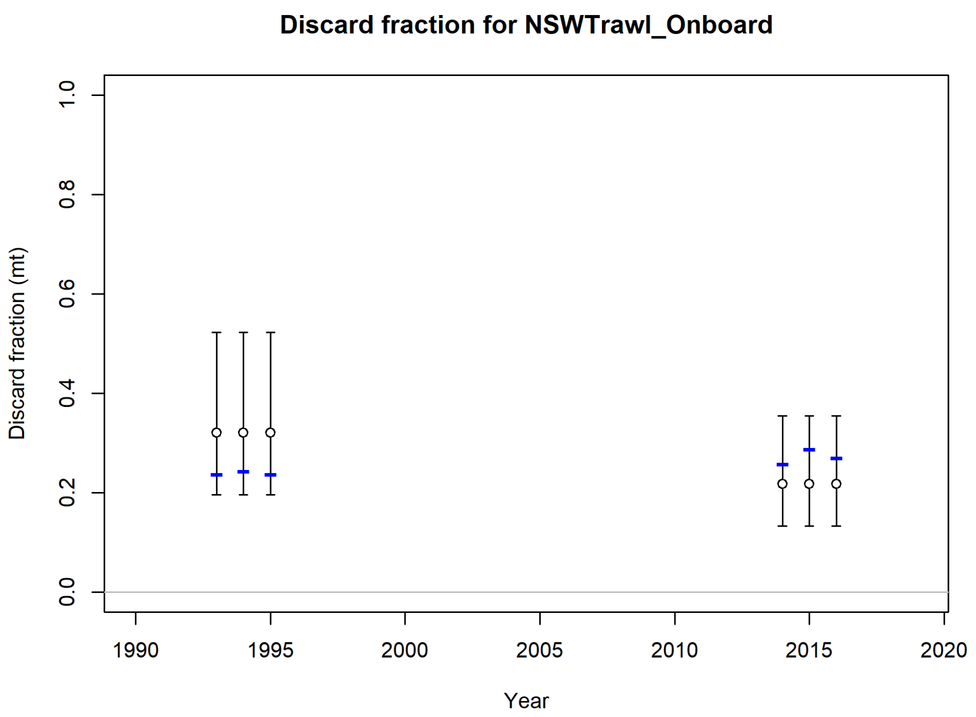


Figure 22. Observed (circles) and model-estimated (blue lines) discard estimates versus year for the Victorian Danish seine fleet (top) and the trawl fleet (bottom), with approximate 95% asymptotic intervals.



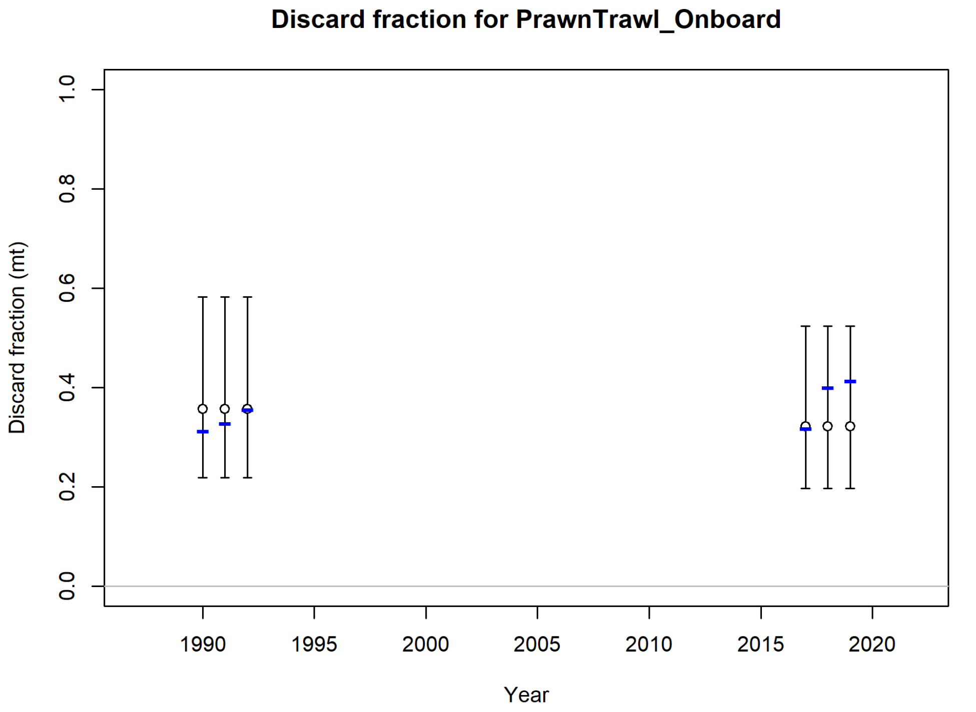


Figure 23. Observed (circles) and model-estimated (blue lines) discard estimates versus year for the NSW trawl fleet (top) and the prawn trawl fleet (bottom), with approximate 95% asymptotic intervals.

The base-case model is able to fit the retained, whole and discarded length-frequency distributions adequately (Figure 24 and Appendix A), with the exception of the discards from the trawl and NSW trawl fleets. 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 24). The fits to the whole length frequencies (trawl, NSW trawl and prawn trawl) are not quite as good as other fits, but this is difficult given the mix of retained and discarded fish (Figure 24).

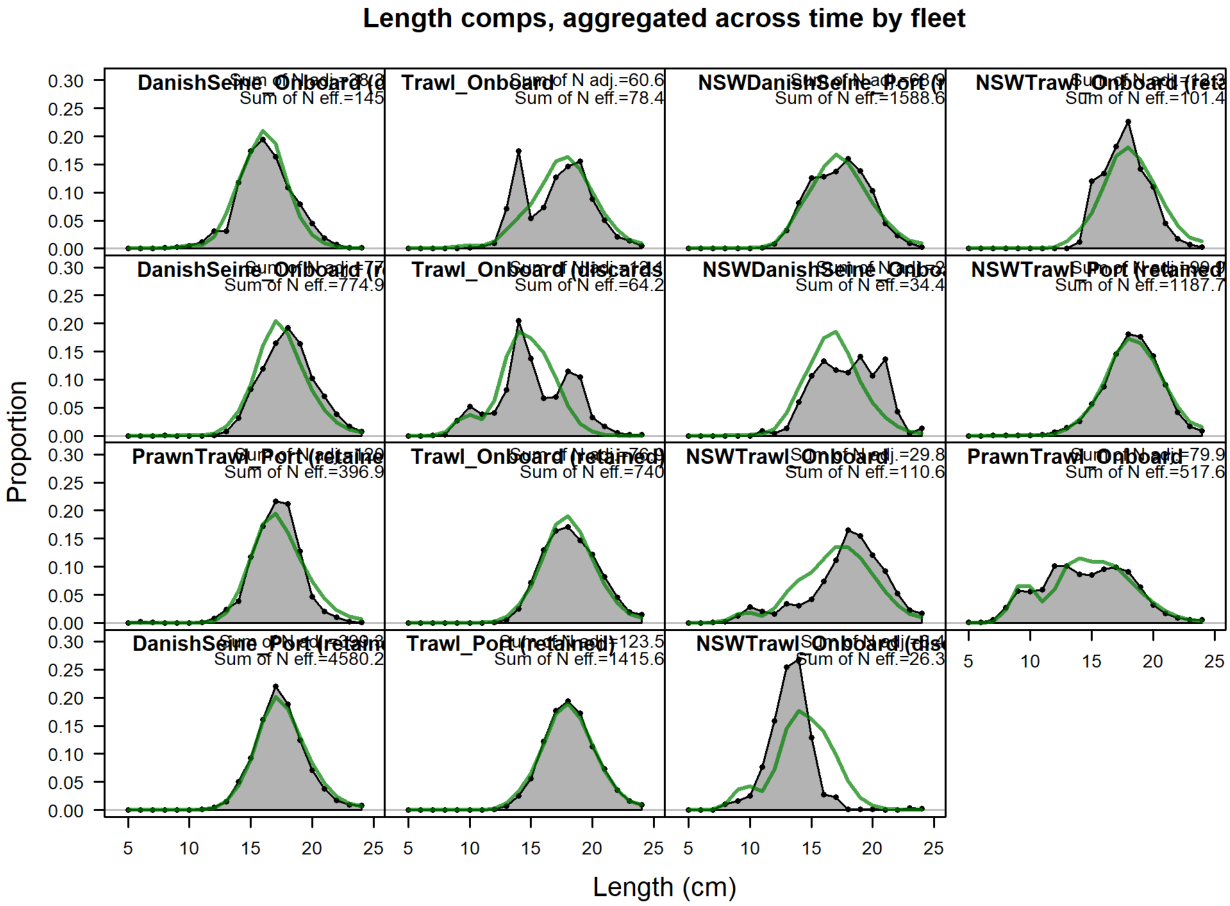


Figure 24. Fits to retained, whole and discarded length compositions by fleet, separated by port and onboard samples, aggregated across all years. Observed data are grey and the fitted value is the green line.

The implied fits to the age composition data are shown for the Victorian Danish seine and trawl fleets 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 these two fleets.

The conditional age-at-length data is noisy between years, with occasionally quite large changes in mean age between adjacent years, in some instances larger changes than would have been expected through biology and fishing mortality. The mean age varies between two and four years for both the Danish seine and trawl fleets (Appendix Figures A.46-A.49) and between 1½ and 2½ years for prawn trawl (Appendix Figures A.50). This variability in the age-at-length data is likely to be due to spatial or temporal variation in collection of age samples. Fits to the conditional age-at-length data 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.

The contributions to the total negative log likelihood by fleet and data source is shown in Table 13. This gives an indication of the contribution to the total negative log likelihood from different data components. These likelihood components decrease as the fit improves yet increase as the number of data points used for this fit increases, so a direct comparison is not always useful. The daily and monthly CPUE series for NSW trawl and prawn trawl have the same number of data points, so in this case, the lower values (negative, but larger in absolute magnitude, in this case) for the NSW trawl CPUE component indicates a better fit than for the respective the prawn trawl components, for both the monthly and daily series. Comparing the Victorian and trawl CPUE series is more nuanced as there are 34 data points for the Victorian Danish seine and only 25 data points for the NSW trawl. However, in this case, given that the quantity for the Victorian Danish seine is smaller and this comes from more data points, the fit is clearly better for the Victorian Danish seine CPUE. For the length data the NSW Danish seine onboard data comes from only one year, compared to 11 years of data from NSW Danish seine port measurements. In this case, comparing the likelihoods of these two components gives no information on the better fits to the data.

Table 13. Negative log likelihood contributions by fleet and data source.

Likelihood component	Discard	Length	Age	CPUE
Fleet				
Victorian Danish seine (onboard)	25.5	29.7	70.6	-41.3
Victorian Danish seine (port)		33.2		
Trawl (onboard)	22.9	38.7	37.8	-24.3
Trawl (port)		17.2		
NSW Danish seine (onboard)		0.4		
NSW Danish seine (port)		10.7	36.7	
NSW trawl (onboard/monthly)	-5.0	9.7	87.6	-14.5
NSW trawl (port/daily)		14.2		-15.0
prawn trawl (onboard/monthly)	-7.2	12.9	26.9	-11.6
prawn trawl (port/daily)		19.8		-10.1

3.2.3 Assessment outcomes

The current spawning stock biomass (Figure 25) is estimated to be 41% of unfished spawning stock biomass (i.e. 2021 spawning biomass relative to unfished spawning biomass), with some uncertainty (with 95% asymptotic intervals ranging from around 35% to 45%). The stock declines slowly from the beginning of the fishery in 1942, before a sharp decline in the 1980s corresponding to an increase in catch. The stock status then varied between around 30% to 50% unfished spawning stock biomass from 1992 (Figure 25). In 1999 the stock declines to a low of 28% SSB_0, then increases to over 40% SSB_0 between 2006 and 2009, followed by another decline to 29% SSB_0 in 2014, and then varying between around 30% and 40% SSB_0 since then (Figure 25). The increase in stock status from 1999 to 2007 occurred during a period of general decline in total catches starting in the mid 1990s and lasting around 25 years (Figure 1, Table 2). This rebound in spawning stock biomass from 1999 to 2008 also appears to have been boosted by good recruitment in 1999, 2003 and 2005 (Figure 26).

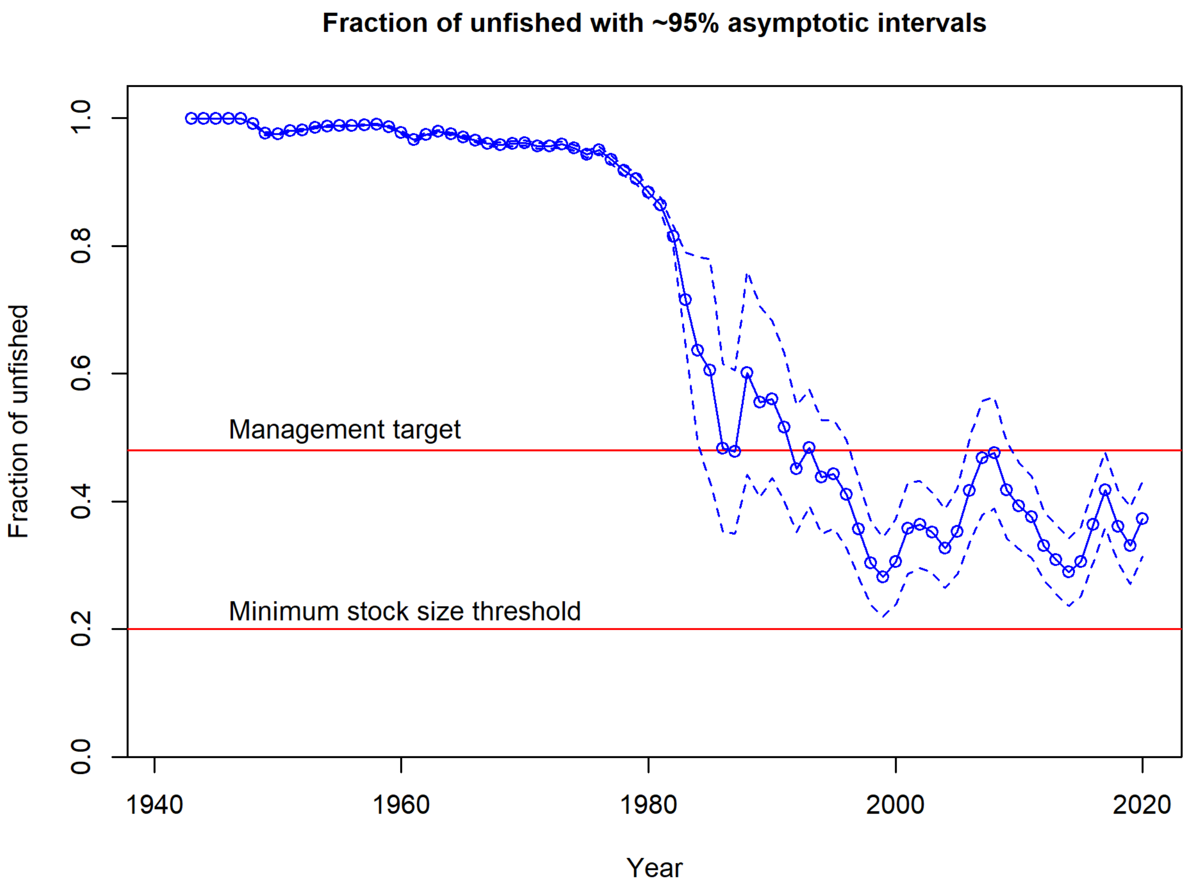


Figure 25. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for the base-case analysis for School Whiting.

The recoveries in the late 1980s and in the early 2000s are driven by higher recruitment events, especially in the mid 1980s (Figure 25, Figure 26). Generally above average recruitment from 1998-2005 allowed a recovery in the stock from a depletion of 28% in 1999 to a depletion of 48% in 2008 (Figure 25, Figure 26). The seven-year period of relatively poor recruitment from 2006 to 2012, is likely to be largely responsible for the decline to 29% SSB_0 in 2014 (Figure 25 Figure 26). This was followed by a recovery to 42% in 2017, following three years of above average recruitment (Figure 25, Figure 26). However, the increased catches since 2017 are most likely to be responsible for the decline from 42% to 33% from 2017-2019 (Figure 25). The most recent years of estimated recruitment are generally informed by less data than earlier years, and hence could potentially be revised with the inclusion of additional data in a future assessment.

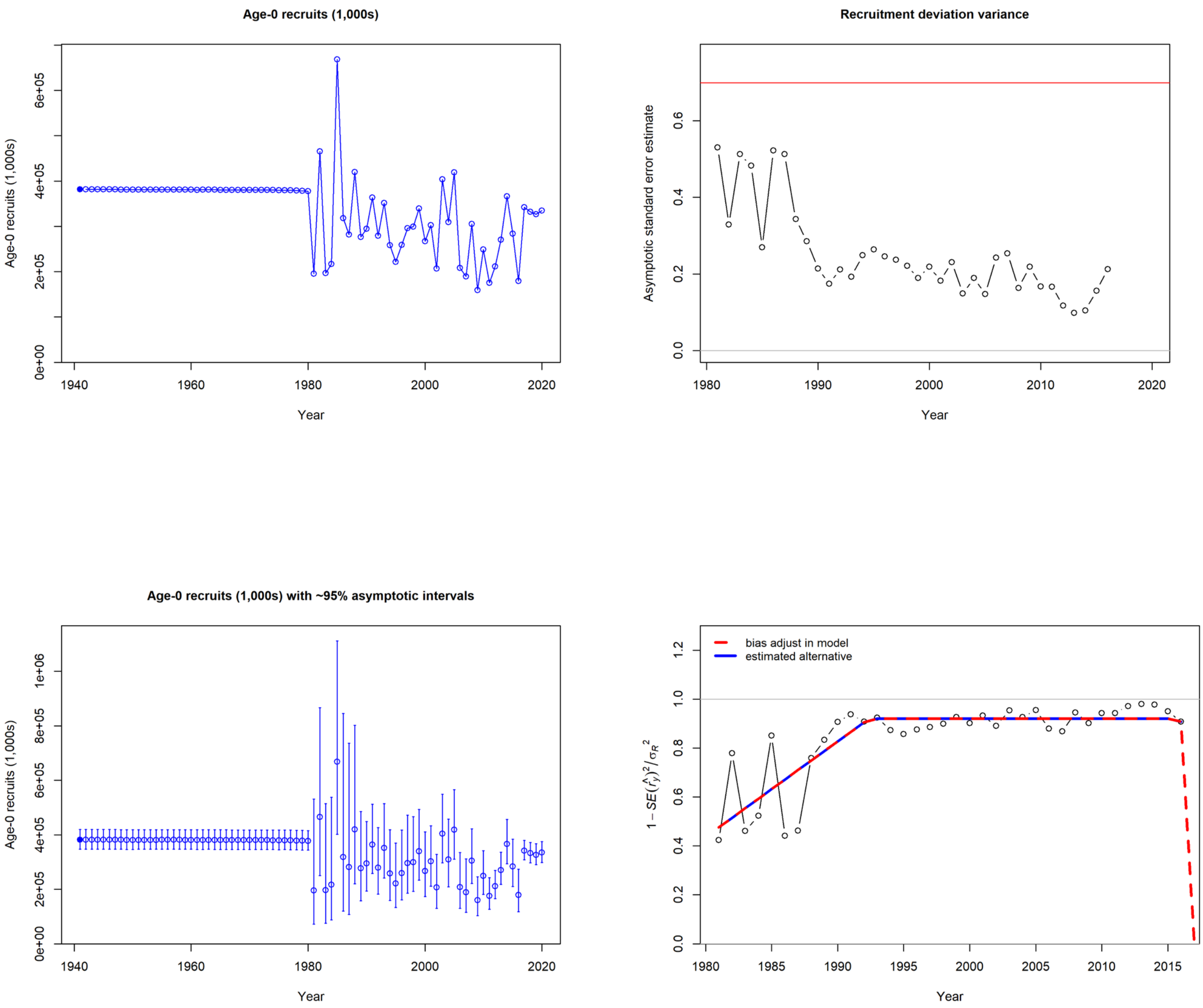


Figure 26. Recruitment estimation for the base case analysis. Top left : Time-trajectories of estimated recruitment numbers; top right : the standard errors of recruitment deviation estimates; bottom left : time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; bottom right: bias adjustment.

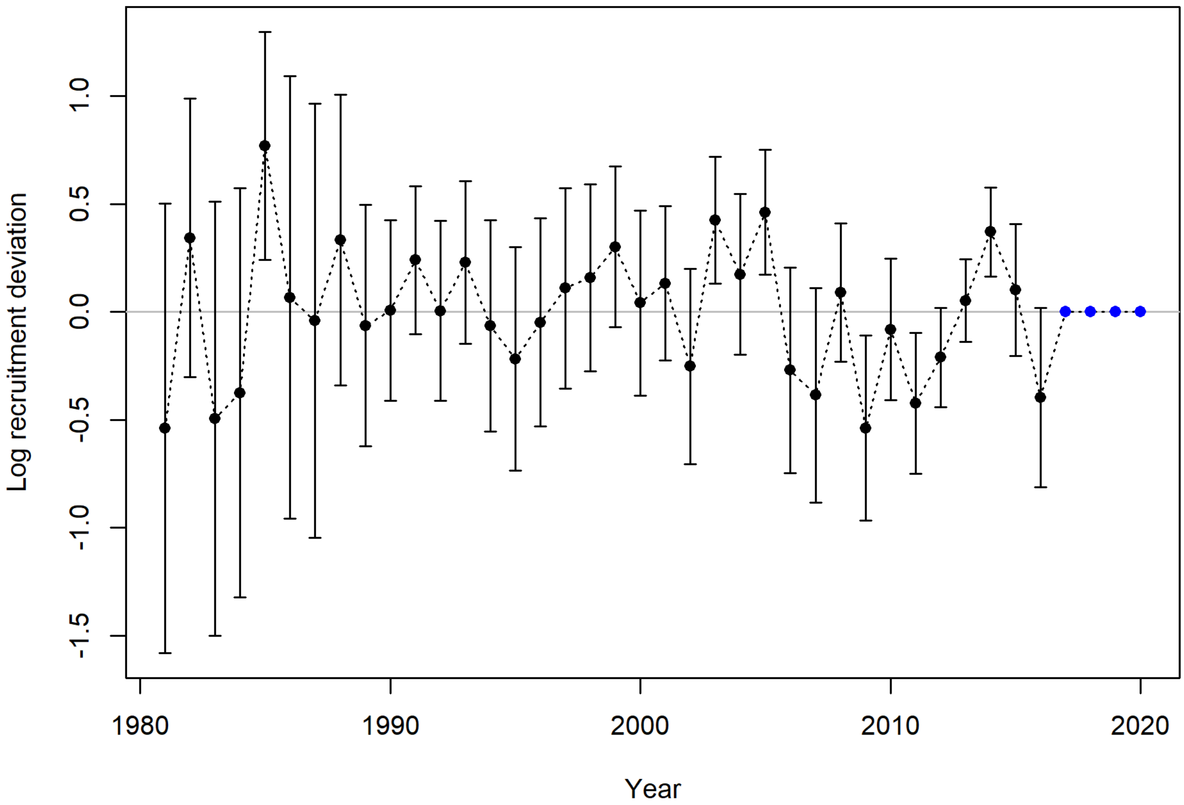


Figure 27. Time trajectory of estimated recruitment deviations with 95% confidence intervals.

The time-trajectories of estimated recruitment and estimated recruitment deviations are shown in Figure 26 and Figure 27. Estimates of recruitments since 1981 are variable (Figure 27) with large estimated recruitment events in 1982 and 1985. This is followed by a period of generally average or above average estimated recruitment between 1986 and 2005, when the mean estimated recruitment deviation is 0.10, and a period of below average recruitment from 2006 to 2012 when the mean estimated recruitment deviation is -0.26.

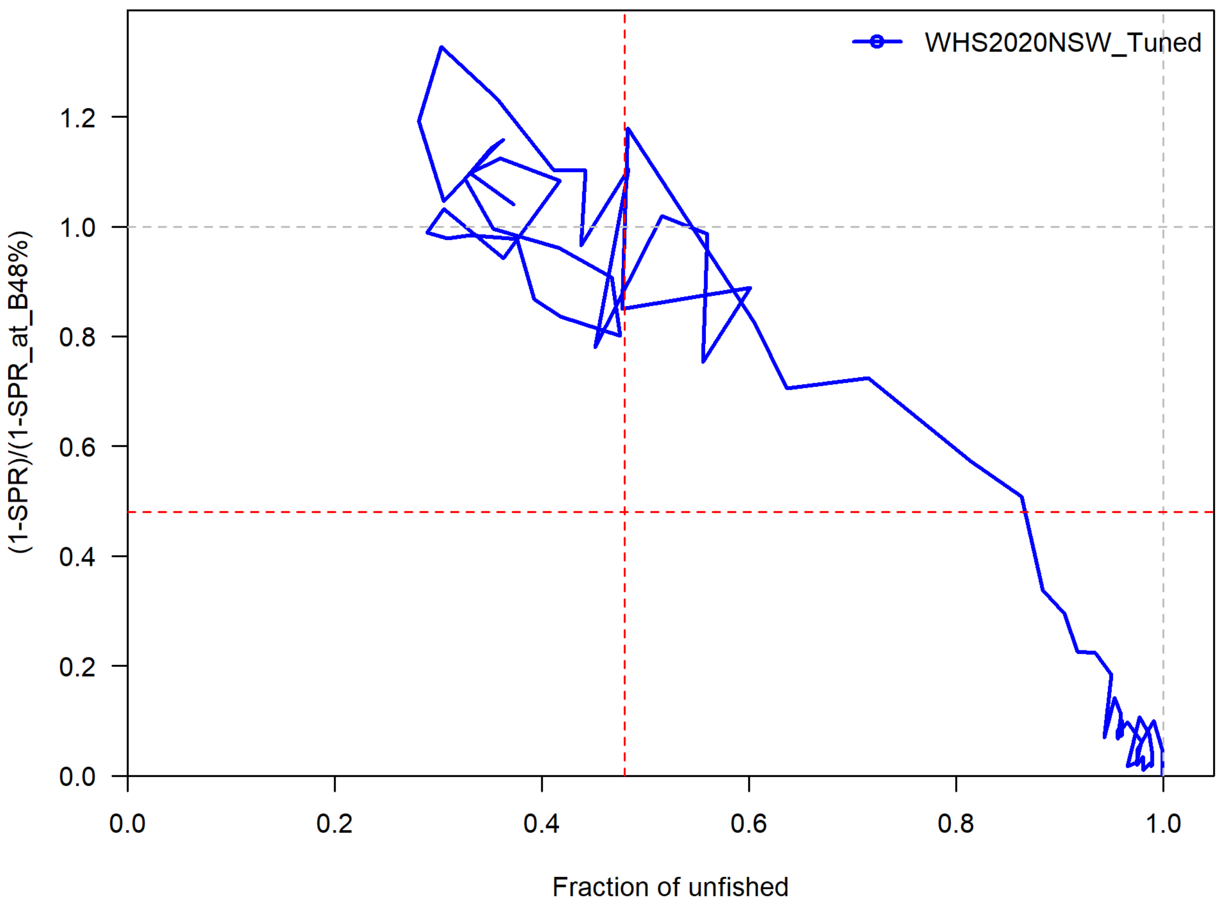


Figure 28. Kobe plot showing the trajectory of spawning biomass (relative to B_0) plotted against 1-SPR ratio, which is a proxy for fishing mortality, integrating fishing mortality across fleets in the fishery.

Figure 28 shows a Kobe plot for the five-fleet model. 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 2019 where the biomass is below the target (around 40%, to the left of the vertical red dashed line) and the fishing mortality is above the target fishing level (above the horizontal grey dashed line). This trajectory shows an increase in overall fishing mortality as the fishery developed from 1942, 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 spawning potential ratio is also plotted against year (Figure 29), which shows the time series above and below the target fishing mortality more clearly. Fishing mortality was gradually reduced from the late 1990s and had been below the "overfishing limit" for 11 out of the last 15 years. However, fishing has been above the "overfishing limit" for four of the last five years (Figure 29).

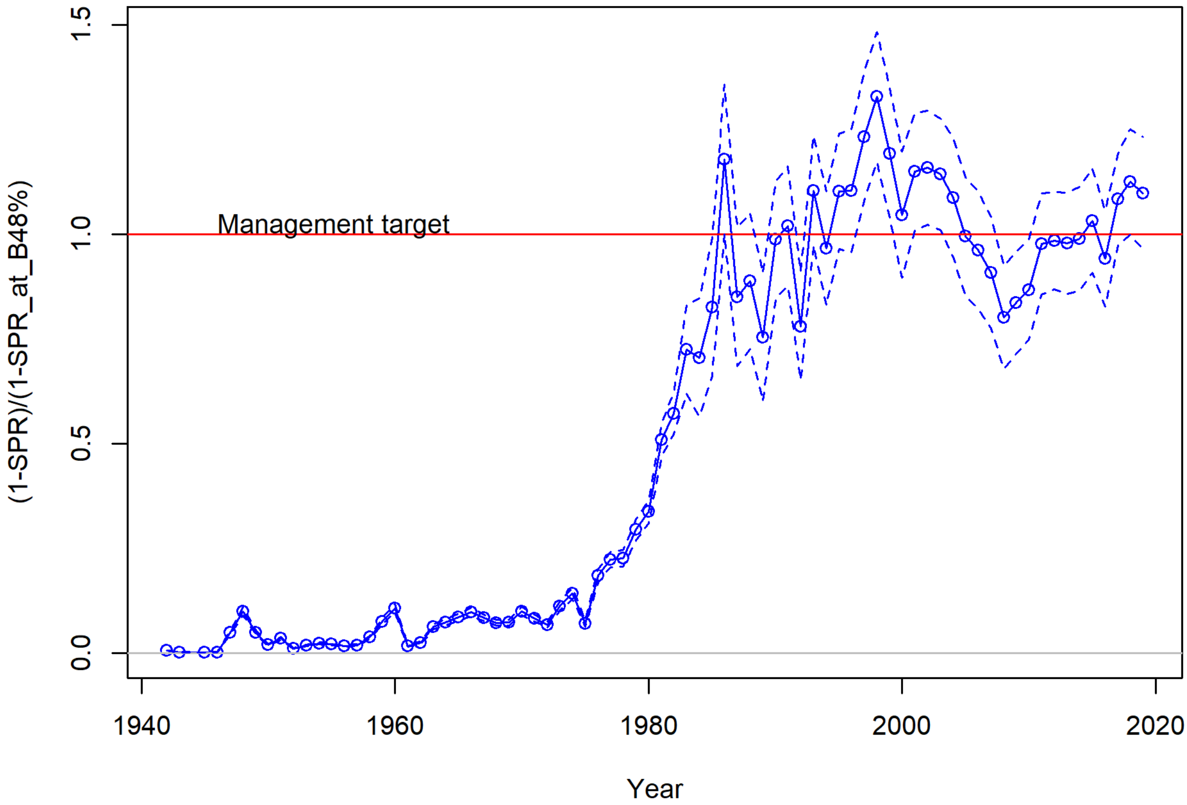
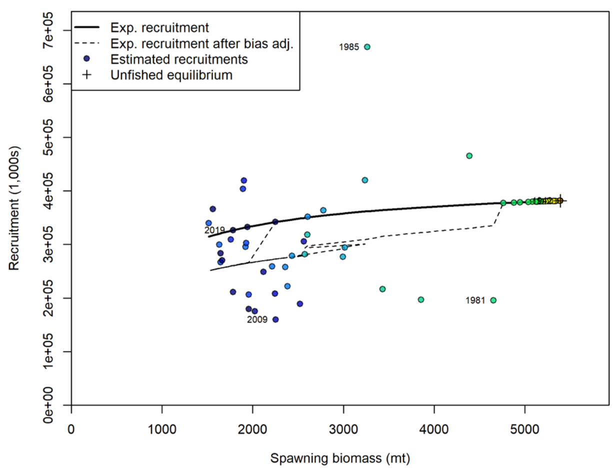


Figure 29. Time series of 1-SPR ratio, a proxy for fishing mortality, integrating fishing mortality across fleets in the fishery.



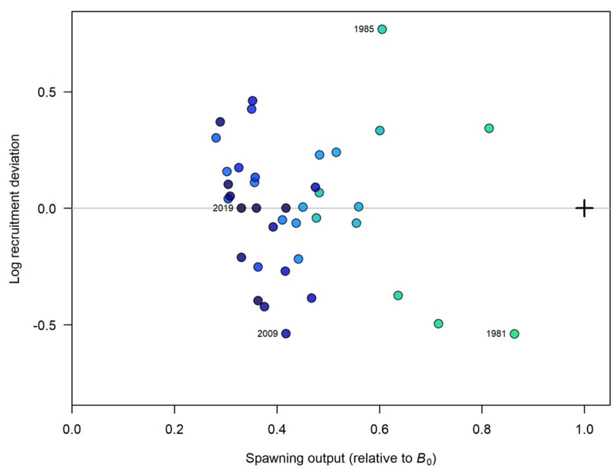


Figure 30. Recruitment estimation for the base case analysis. Left: the stock-recruit curve and estimated recruitments; right: log recruitment deviations from the stock recruitment curve.

The base-case assessment estimates that current spawning stock biomass is 41% of unexploited spawning stock biomass (*SSB_0*). The 2021 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 2,140 t (Table 14) and the long-term yield (assuming average recruitment in the future) is 2,448 t (Table 15). The RBCs for the base case are listed for each individual year from 2021-2025 in Table 14. The RBC averaged over the three-year period of 2021-2023 is 2,237 t (Table 15) and over the five-year period 2021-2025, is 2,295 t (Table 15).

Table 14. Yearly projected RBCs (tonnes) across all fleets under the 20:35:48 harvest control rule assuming average recruitment from 2017.

Year	RBC (t)
2021	2,140
2022	2,250
2023	2,321
2024	2,368
2025	2,398

Table 15. Projected recommended biological catches (RBCs) for the five-fleet model for: 2021; the three-year average from 2021-2023; the five-year average for 2021-2025; and the long-term RBC (from 2039).

Period	RBC (t)
1-year: 2021	2,140
3-year average: 2021-2023	2,237
5-year average: 2021-2025	2,295
long-term: 2039	2,448

Spawning biomass (plotted as spawning stock status, a percentage of unexploited spawning stock biomass), recruitment (plotted as a percentage of initial recruitment) and total catch (retained plus discarded) are plotted together in Figure 31 to assist in considering coherence of the model outputs. In the late 1980s, when there is little other data to inform estimates of recruitment deviations, the estimates of recruitment are correlated (with a lag) with removals, enabling improved fits to the model by associating large recruitment events, such as 1985 and 1988 with subsequent large removals, 1986 and 1990/1991. As additional length and age information is available to inform estimates of recruitment deviations, this strong relationship between high removals and high recruitment breaks down.

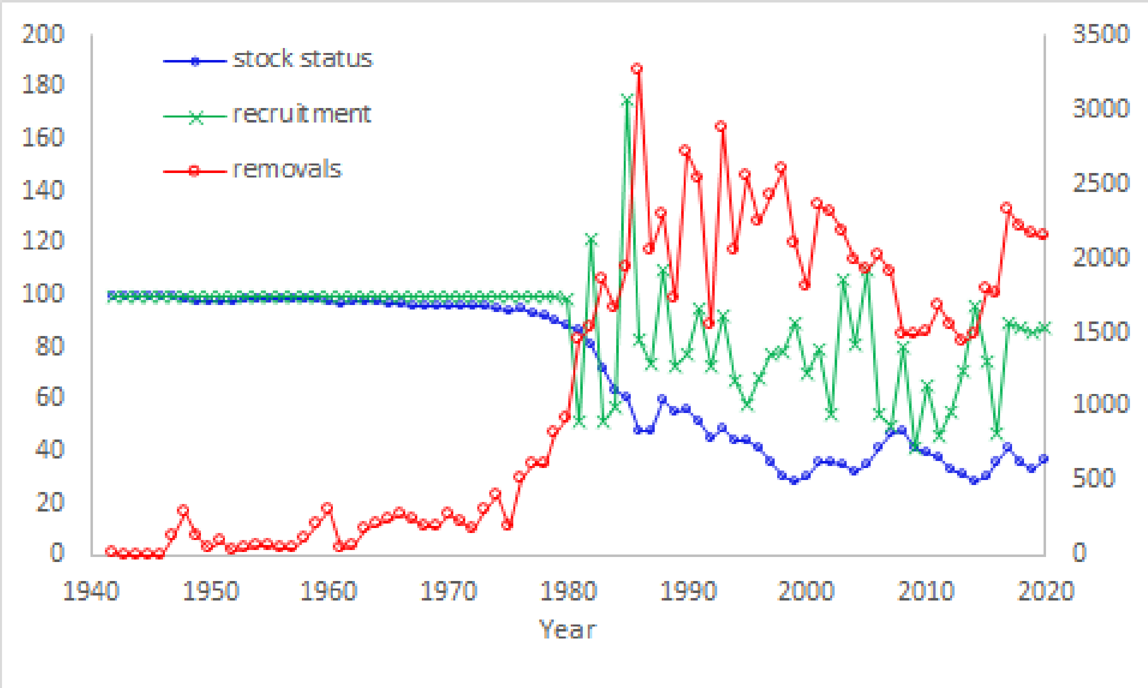


Figure 31. Time series of spawning stock status, recruitment and total catch (removals), including both landed catches plus discards.

3.2.4 Discard estimates

Model estimates for discards for the period 1942-2019 are listed in Table 16. The model predicted discards for 2020 are based on an assumed catch in 2020 equal to the 2019 catch and are projected for the period 2021-25 using the catches determined by the RBC set from the 20:35:48 Harvest Control Rule. The average discard for the three-year period from 2021-2023 is 378 t and for the five-year period from 2021-2025, the average is 384 t.

Table 16. Model estimated discards (tonnes) by year, summed across all fleets, using projected discards from 2021 using the 20:35:48 harvest control rule with catches set to the RBC for each year from 2021 to 2025 and the 2020 catch set equal to the 2019 catch. The discards in blue are model estimated discards from projected catches, with the 2020 projected catch set equal to the 2019 catch, and subsequent catches set at the RBC.

Year	Discards	Year	Discards	Year	Discards	Year	Discards
1942	2	1963	13	1984	261	2005	511
1943	1	1964	17	1985	248	2006	508
1944	0	1965	21	1986	768	2007	372
1945	0	1966	27	1987	363	2008	240
1946	1	1967	23	1988	326	2009	259
1947	5	1968	14	1989	216	2010	257
1948	11	1969	10	1990	268	2011	278
1949	5	1970	13	1991	306	2012	243
1950	2	1971	13	1992	208	2013	227
1951	4	1972	12	1993	363	2014	248
1952	1	1973	17	1994	321	2015	370
1953	2	1974	22	1995	395	2016	281
1954	2	1975	11	1996	407	2017	353
1955	3	1976	42	1997	567	2018	415
1956	2	1977	68	1998	741	2019	410
1957	3	1978	64	1999	578	2020	388
1958	6	1979	79	2000	457	2021	370
1959	11	1980	120	2001	551	2022	379
1960	15	1981	164	2002	547	2023	386
1961	5	1982	191	2003	485	2024	390
1962	7	1983	330	2004	572	2025	393

3.3 Likelihood profiles

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments “fix” key parameters such as mortality (*M*) and steepness (*h*) based on a priori considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value or indeed support for estimating that parameter. If the parameter is within the entire range of the 95% confidence interval (within 1.92 units of likelihood), this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Likelihood profiles were constructed for the updated three-fleet model (Day *et al.* 2020) for mortality, steepness, unexploited spawning biomass, 2019 spawning biomass and relative spawning biomass. These were presented to the October 2020 SERAG meeting. New likelihood profiles for the most important of this set, mortality and 2019 relative spawning biomass, were also constructed for the five-fleet model. All of these likelihood profiles are presented in this report.

3.3.1 Three-fleet model likelihood profile: natural mortality

For School Whiting, the likelihood profile for natural mortality, *M*, a parameter estimated in the three-fleet model at 0.68 yr^{-1}, is shown in Figure 32 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests that there is little information in the model that can be used to inform this parameter, due to the flat profile, especially between 0.55 and 0.9 and the broad range of plausible values (95% confidence intervals ranging from 0.5 to greater than 1). The index and age data both suggest higher mortality (mostly through the Danish seine fleet, Figure 33) and are in conflict with the discard data which suggest lower mortality (mostly through the trawl fleet, Figure 33). None of these data sources have strong information to inform an estimate of *M*. If this three-fleet model structure is to be used in future, it would be sensible to fix the value of natural mortality at 0.6, which is the value used when this parameter was last fixed in an assessment (Day 2008).

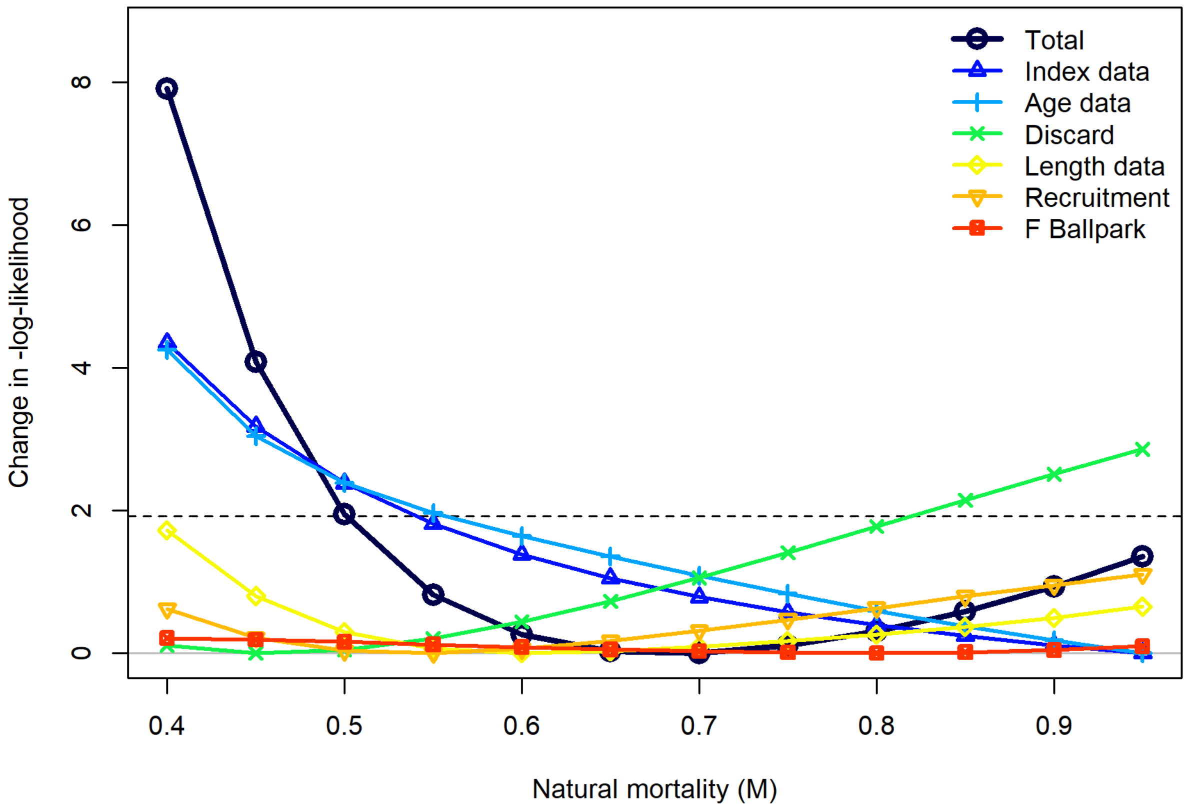


Figure 32. The likelihood profile for natural mortality for the three-fleet model, with *M* ranging from 0.4 to 0.95. The estimated value for *M* in the three-fleet model is 0.68 yr^{-1}.

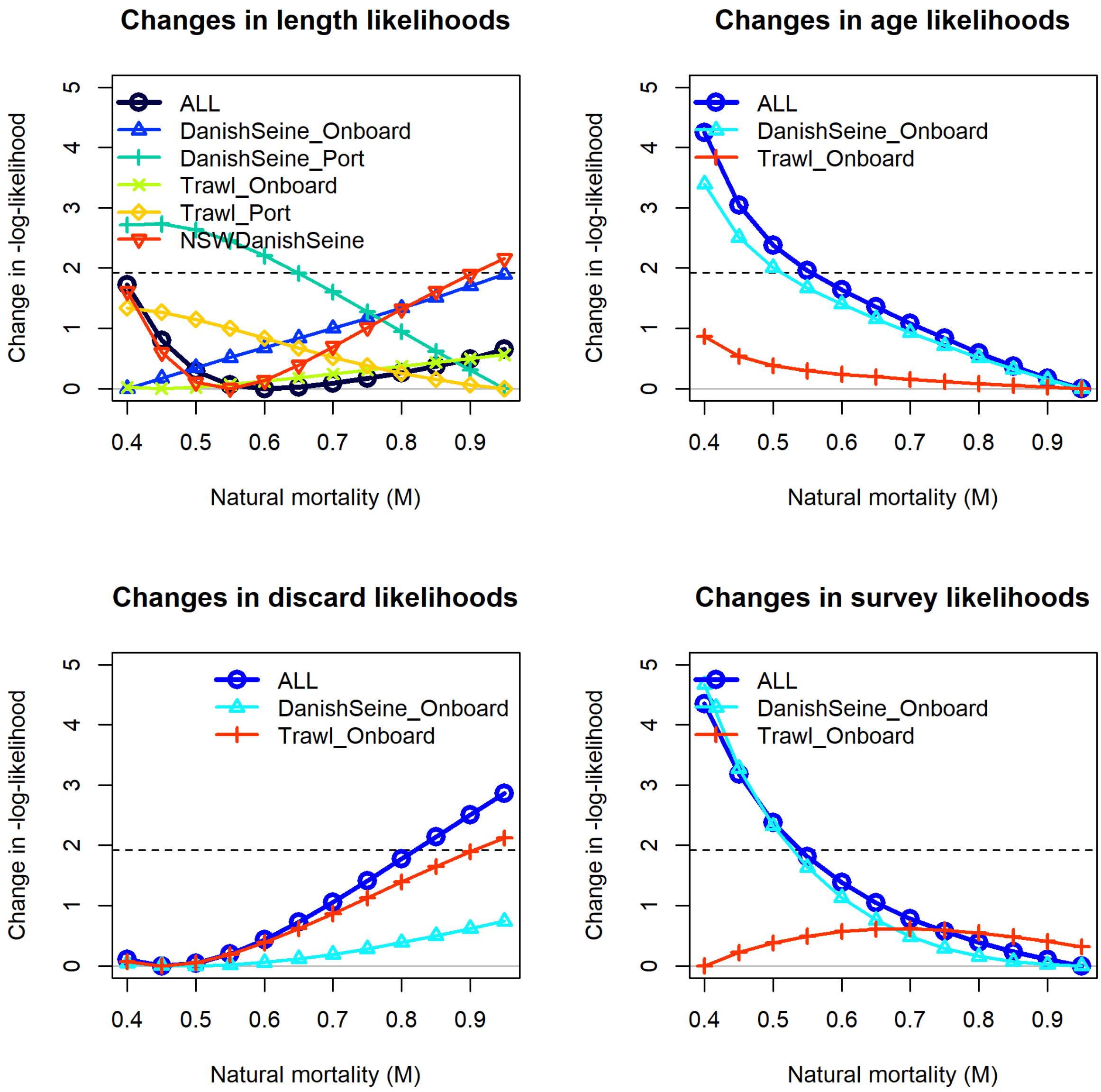


Figure 33. Piner plot for the likelihood profile for natural mortality for the three-fleet model, showing components of the change in likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

3.3.2 Three-fleet model likelihood profile: steepness

For School Whiting, the likelihood profile for steepness, *h*, a parameter fixed in the three-fleet model at 0.75, is shown in Figure 34 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile gives information on the components of the data which are most influential in estimating *h* and gives an indication of how precisely *h* can be estimated, and whether *h* should be estimated.

This likelihood profile in Figure 34 is uninformative as it is relatively flat, with very little difference in likelihood values between 0.45 and 0.85. This suggests that there is insufficient information contained in the data used in this model to inform a value for *h*, so this parameter should be fixed in this model. It is common that *h* is unable to be estimated in stock assessment models. There appears to be no benefit in repeating a likelihood profile on *h* for future stock assessments for School Whiting, nor in attempting to estimate this parameter, at least in the foreseeable future.

Of the limited information in the model that can be used to inform steepness, the most influential data sources in providing information on *h* are the length data and discard proportions (Figure 35). While neither data source is that influential, the discard data (mostly through the Danish seine fleet, Figure 35) support a higher value of steepness (a more productive stock) than the length data support a lower values of steepness (mostly through the two Danish seine fleets, Figure 35). The Danish seine fleet generally has more influence than the trawl fleet on all components (Figure 35).

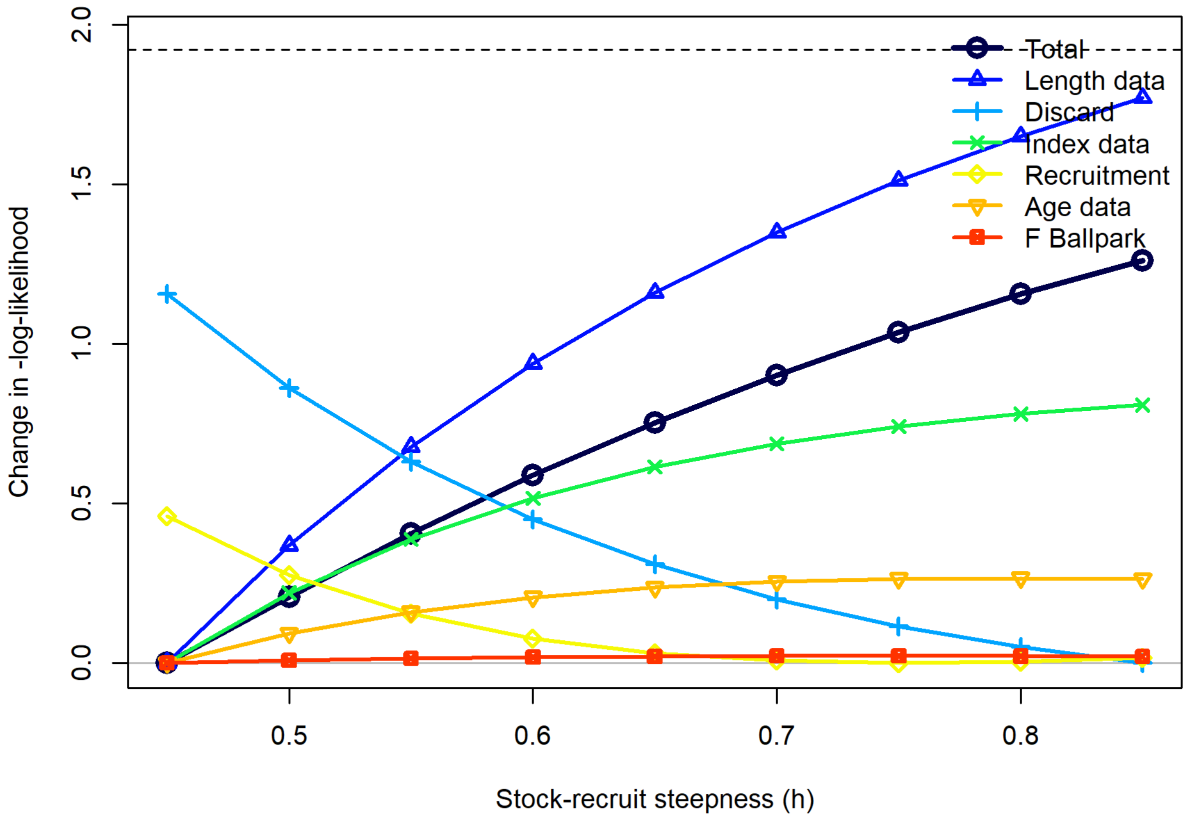


Figure 34. The likelihood profile for steepness (*h)* for the three-fleet model, with *h* ranging from 0.45 to 0.85. The fixed value for *h* in the three-fleet model is 0.75.

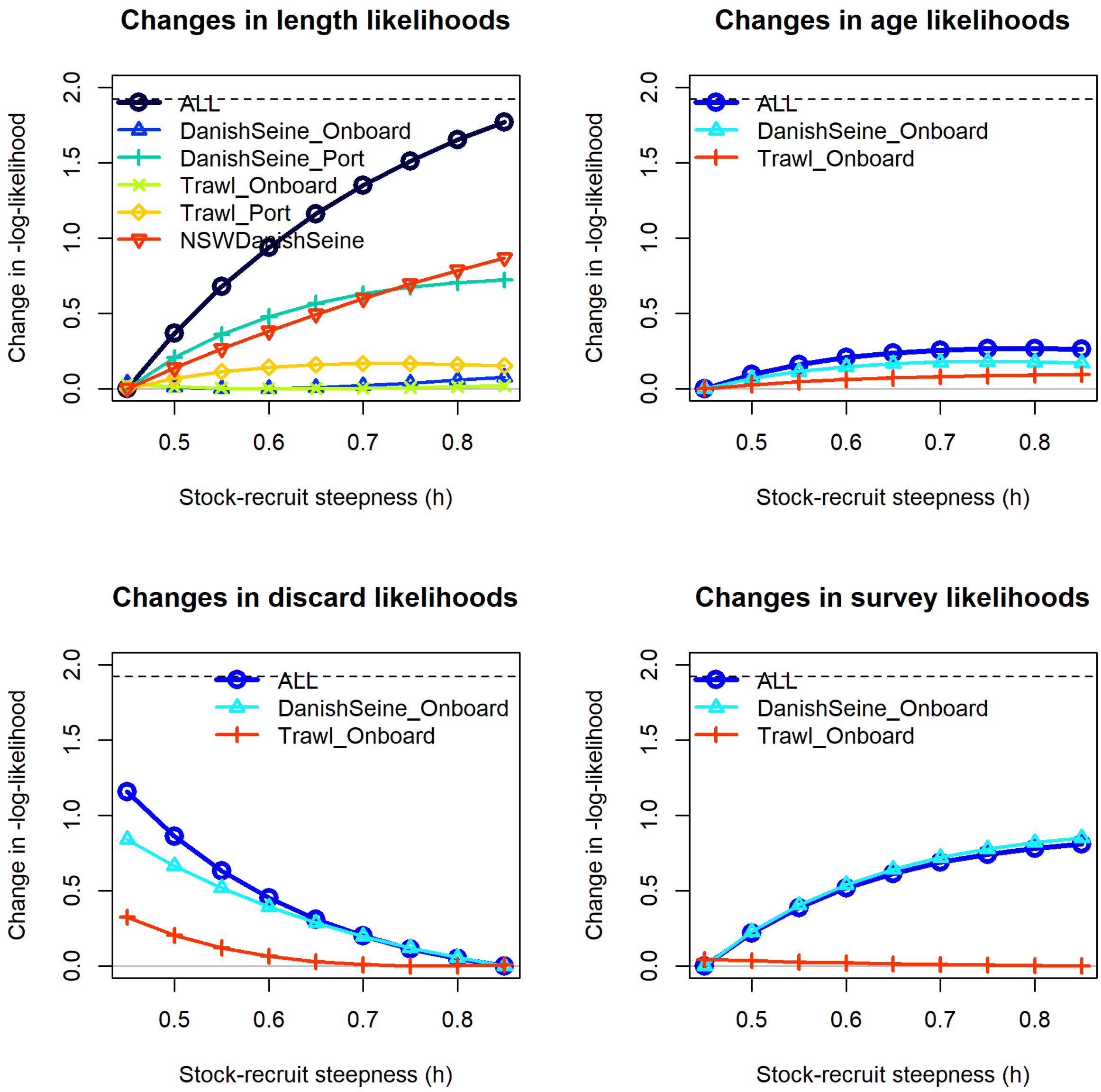


Figure 35. Piner plot for the likelihood profile for steepness for the three-fleet model, showing components of the change in likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

3.3.3 Three-fleet model likelihood profile: unexploited spawning stock biomass

A likelihood profile for unexploited spawning stock biomass (SSB_0) is shown in Figure 36 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. SSB_0 is a derived parameter which is linked to the estimated parameter R_0, which is the average equilibrium recruitment. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 1942) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for SSB_0 ranging between around 8,500 and 19,000 t with the most likely value at around 10,000 t. In contrast, the asymptotics, which make some strong assumptions, suggest a symmetric distribution ranging between 8,000 and 12,000 t.

The important data sources in providing information on SSB_0 are the age data and the discard data (Figure 36). The age data support a higher value for SSB_0, mainly through the Danish seine fleet age data (Figure 37), and the discard data support a lower value for SSB_0, mainly through the trawl fleet discard data. The age data essentially provide a lower bound on SSB_0 while the discard data provide an upper bound. SSB_0 is estimated with considerable uncertainty.

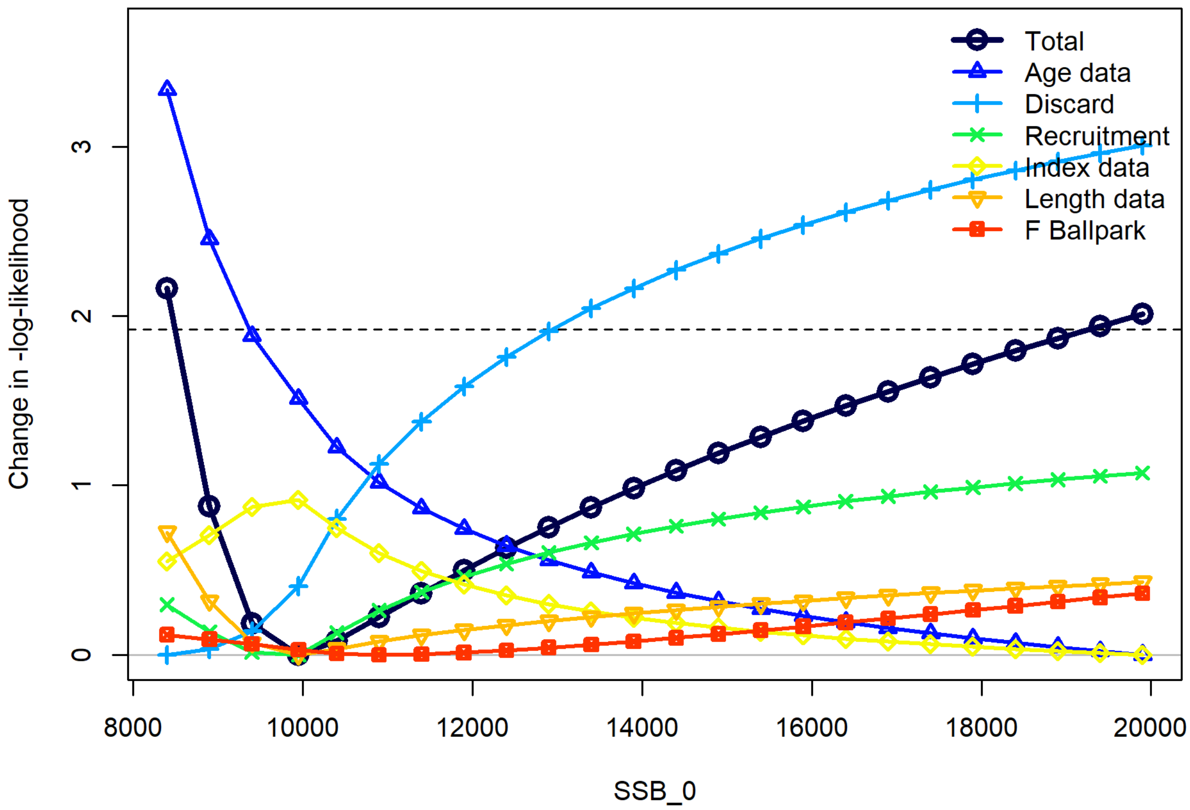


Figure 36. The likelihood profile for unexploited spawning stock biomass for the three-fleet model, with SSB_0 ranging from 8,000 to 20,000 t. The estimated value for SSB_0 is 9,895 t.

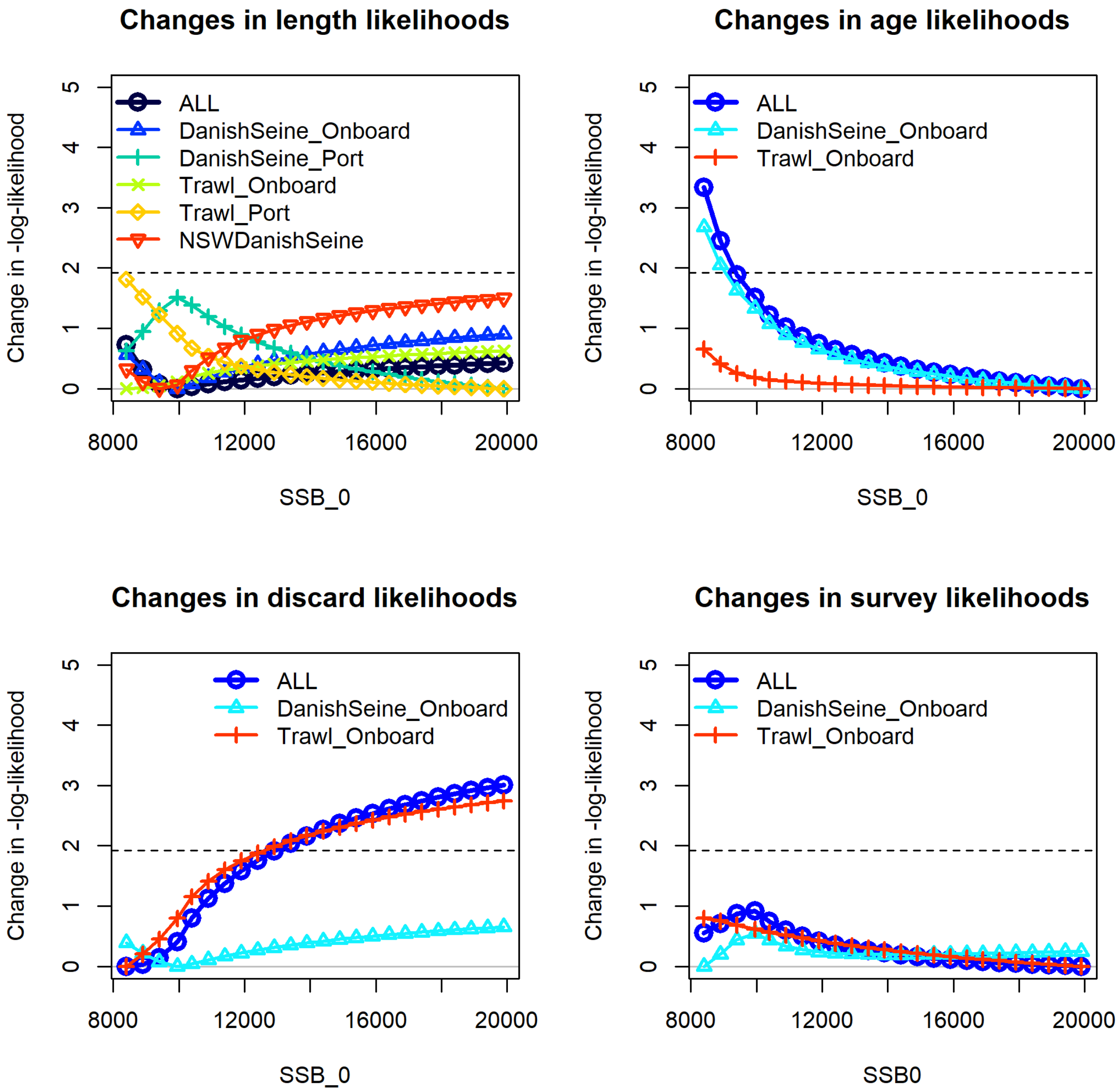


Figure 37. Piner plot for the likelihood profile for unexploited spawning stock biomass for the three-fleet model, showing components of the likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

3.3.4 Three-fleet model likelihood profile: current (2019) spawning biomass

A likelihood profile for current spawning biomass (SSB_{2019}) is shown in Figure 38 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. Like SSB_0, SSB_{2019} is a derived parameter which is linked to the estimated parameter R_0, which is the average equilibrium recruitment. To construct a likelihood profile on SSB_{2019} requires setting up an additional "fleet" with a single data point (in 2019) with very low standard error, essentially adding a "highly precise survey" of spawning biomass, setting the selectivity type to 30 (an index of *SSB*) and then allowing this spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for SSB_{2019} ranging between around 2,000 and 10,000 t with the most likely value at around 3,000 t. In contrast, the asymptotics, which make some strong assumptions, suggest a symmetric distribution ranging between 1,000 and 5,000 t (Figure 7 and Figure 8).

The important data sources in providing information on *SSB₂₀₁₉* are the age and index data and discard data (Figure 38). Both the age and index data support a higher value for *SSB₂₀₁₉*, mainly through data from the Danish seine fleet (Figure 39), while the discard data support a lower value for *SSB₂₀₁₉*, mainly through the trawl fleet discard data (Figure 39). The age and index data essentially provide a lower bound on *SSB₂₀₁₉* while the discard data provide an upper bound. *SSB₂₀₁₉* is estimated with considerable uncertainty.

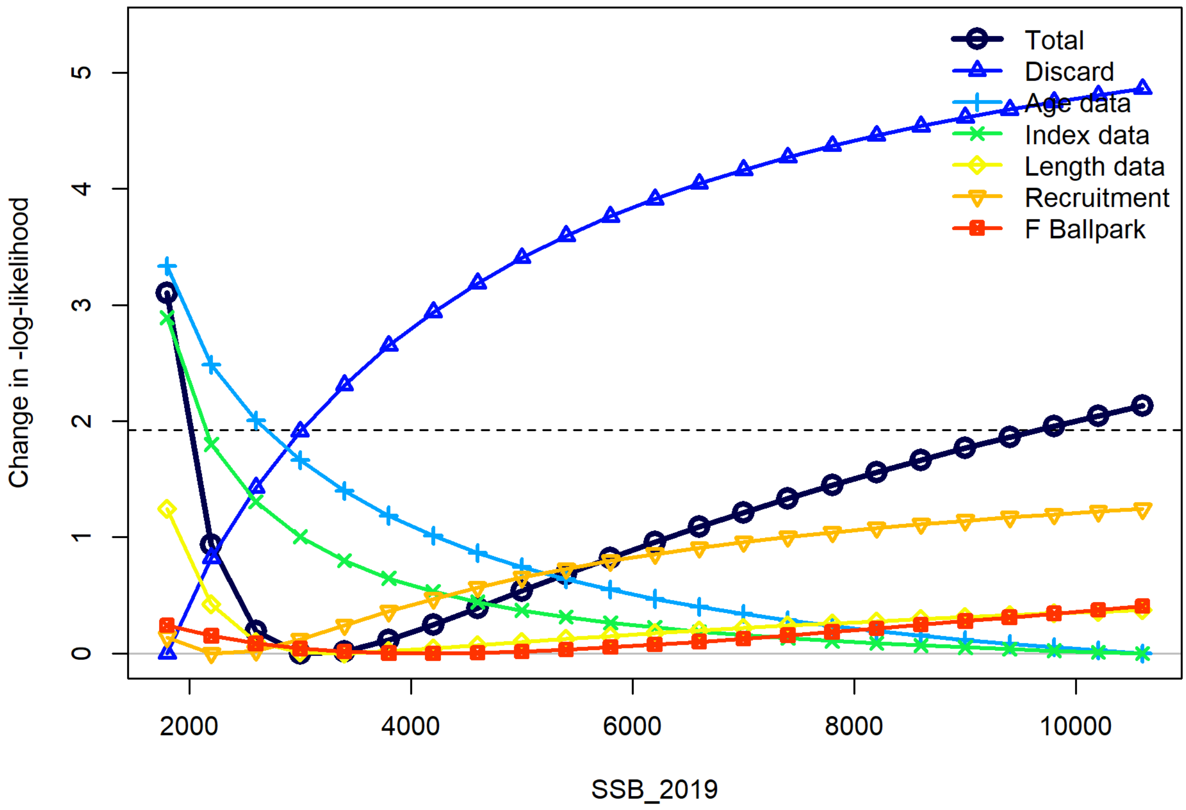


Figure 38. The likelihood profile for 2019 spawning biomass for the three-fleet model, ranging from about 2,000 to 10,000 t. The estimated value for 2019 spawning biomass is 3,137 t.

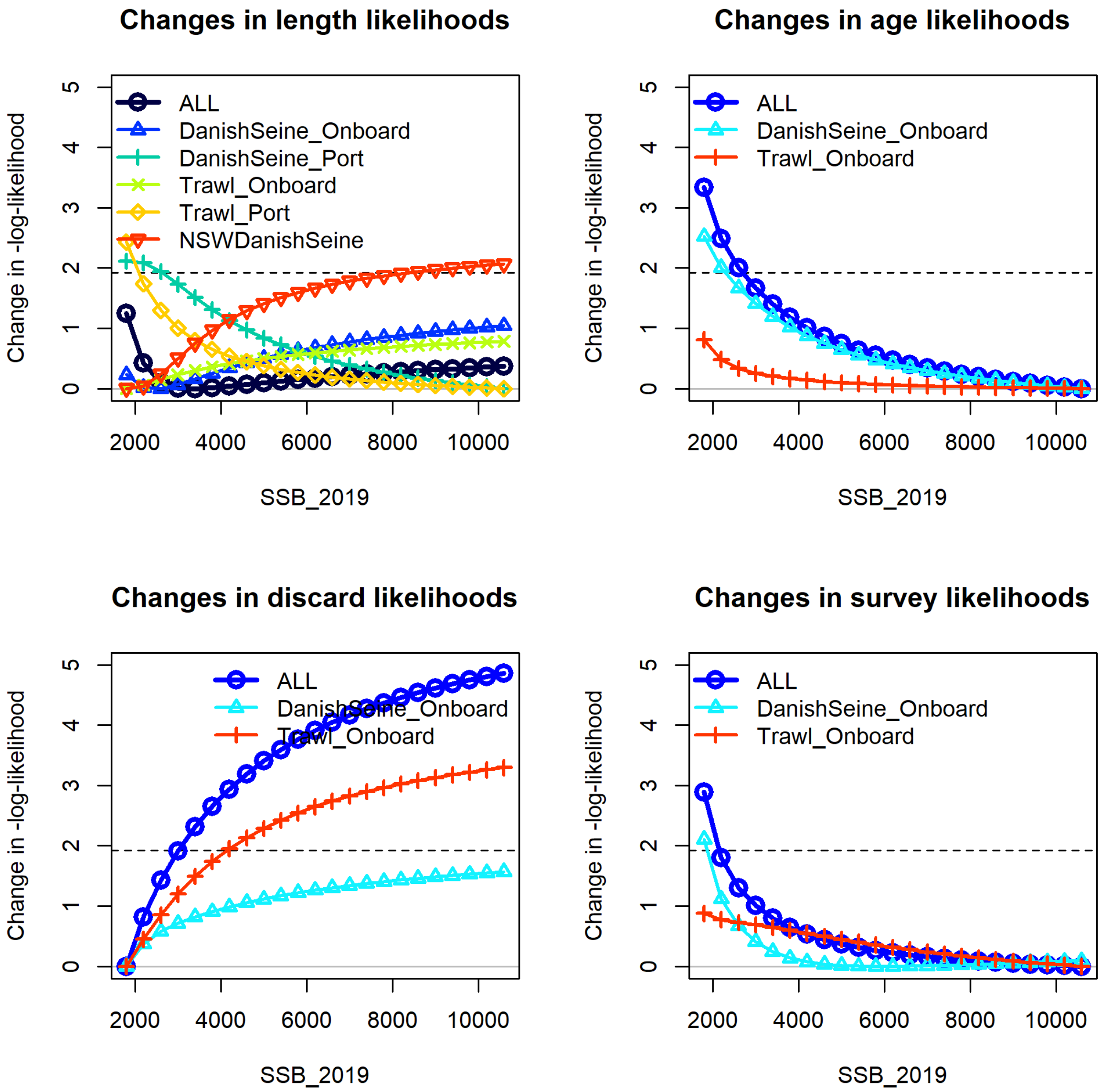


Figure 39. Piner plot for the likelihood profile for 2019 spawning biomass for the three-fleet model, showing components of the change in likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

3.3.5 Three-fleet model likelihood profile: Relative spawning biomass (depletion)

A likelihood profile for current spawning biomass (SSB_{2019}) relative to SSB_0 is shown in Figure 40 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. Like SSB_0 and SSB_{2019}, relative spawning biomass is a derived parameter. To construct a likelihood profile on relative spawning biomass requires setting up an additional “fleet” with a value of 1.0 in 1942 and an additional data point at the end of the series (2019), specifying a depletion level with a very low standard error, essentially adding a “highly precise survey” of depletion, setting the selectivity type to 34 (an index of *SSB*) and then allowing this relative spawning biomass value to vary between runs. This likelihood profile suggests a broad range of plausible values for depletion in 2018 ranging between around 20% and 50%, with the most likely value at around 32%. Discard, age and index have the most influence (Figure 40).

Ideally this likelihood profile would be produced for depletion at the start of 2021, as with the likelihood profile on current biomass (2021 rather than 2019). However, likelihood profiles can only be constructed on parameters that are associated with likelihood values (requiring actual data) and not projected values, so 2019 is the last year that a likelihood profile can be constructed, either for spawning biomass or depletion.

The important data sources in providing information on relative spawning stock biomass are the discard, age and index data (Figure 40). As with current spawning biomass, both the age and index data support a higher value for relative spawning stock biomass, mainly through data from the Danish seine fleet (Figure 41), while the discard data support a lower value for relative spawning stock biomass mainly through the trawl fleet discard data (Figure 39). The age and index data essentially provide a lower bound on relative spawning stock biomass while the discard data provide an upper bound. Relative spawning stock biomass is estimated with considerable uncertainty.

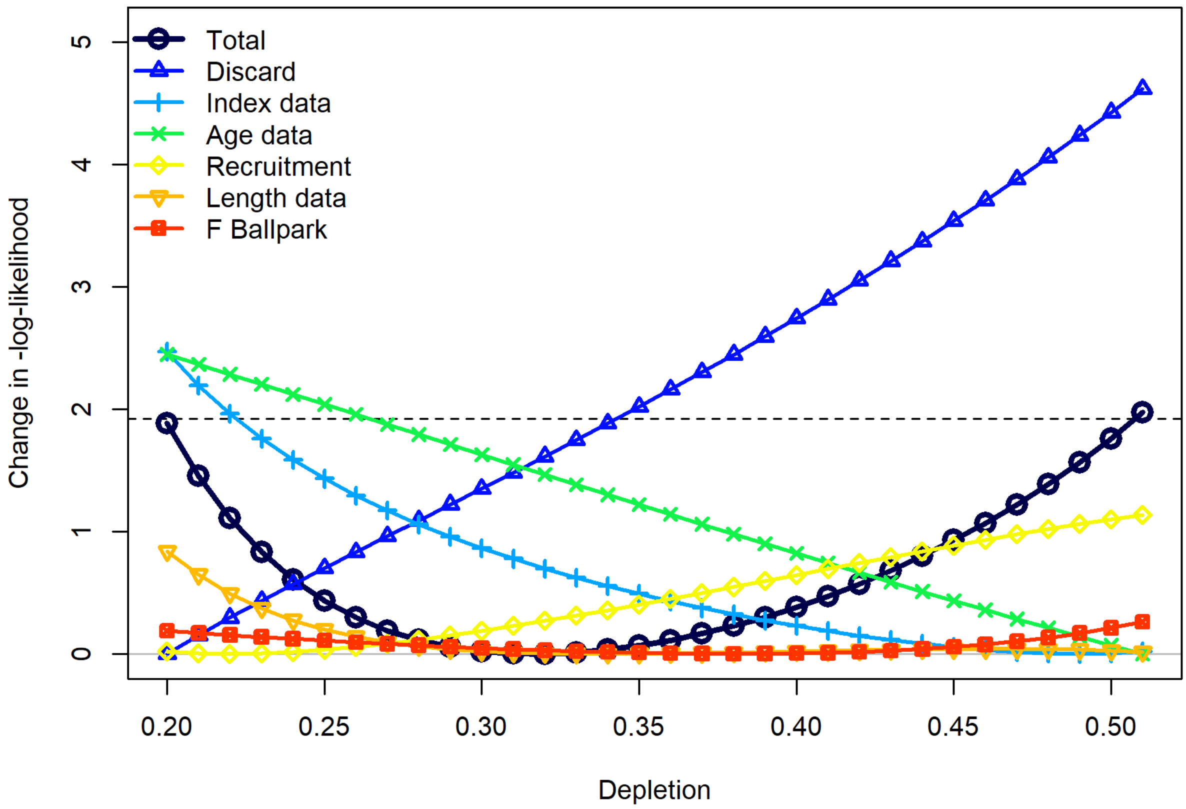


Figure 40. The likelihood profile for relative spawning stock biomass (depletion) in 2019 for the three-fleet model, ranging from about 20% to 45%. The estimated value for depletion in 2019 is 32%.

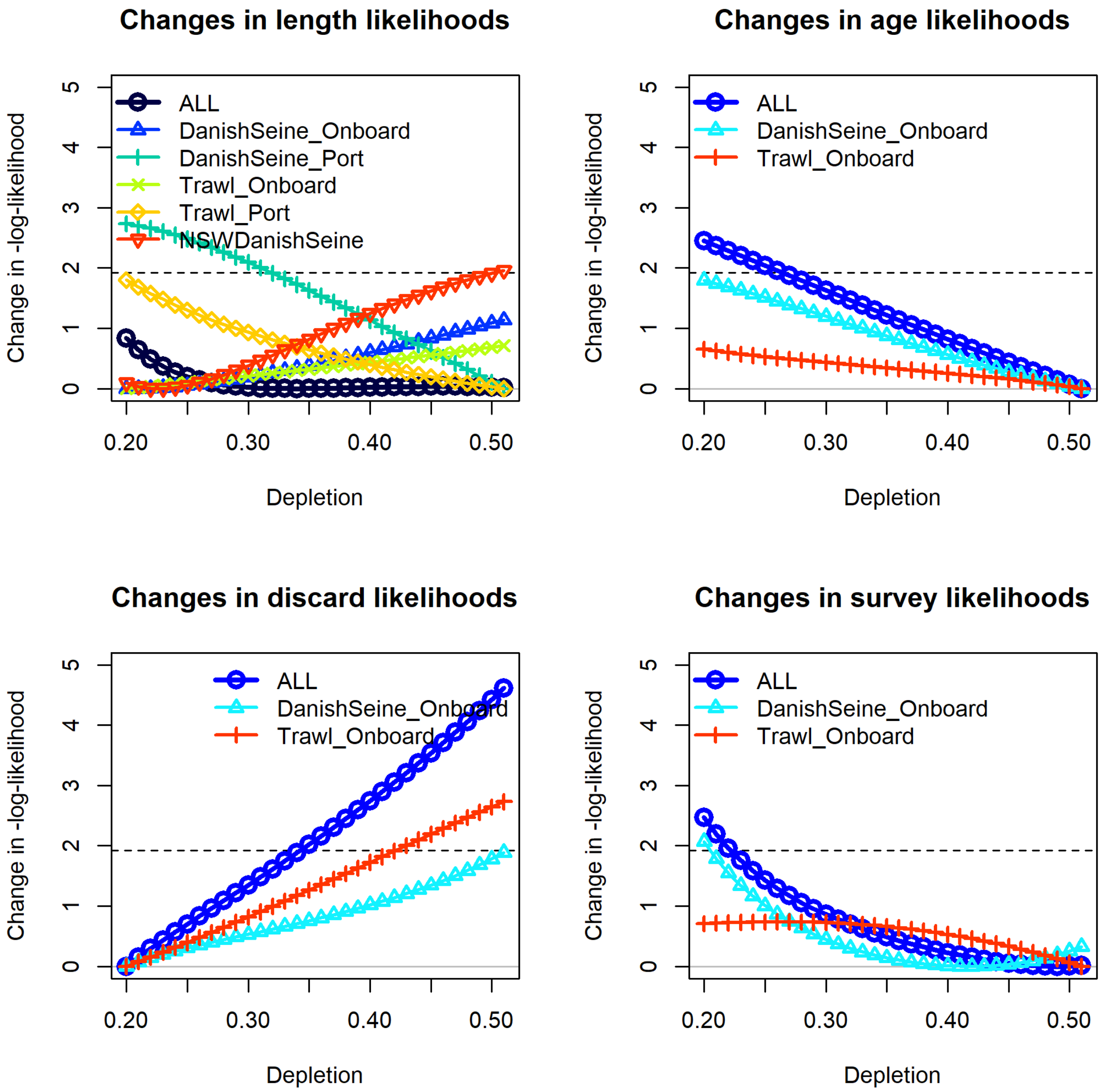


Figure 41. Piner plot for the likelihood profile for relative spawning biomass (depletion) in 2019 for the three-fleet model, showing components of the change in likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

3.3.6 Five-fleet model likelihood profile: natural mortality

For the five-fleet model for School Whiting, the likelihood profile for natural mortality, *M*, a parameter estimated in the three-fleet model, but fixed at 0.6 yr^{-1} in the five-fleet model, is shown in Figure 42, with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests that there is even less information in the model that can be used to inform this parameter, than with the three-fleet model (Figure 32), due to the even flatter profile, especially from 0.65 up to and beyond 0.95, and the broad range of plausible values (95% confidence intervals ranging from 0.65 to considerably greater than 1, beyond the range of values explored). The index, age data and length all suggest higher mortality data (mostly through the Danish seine fleet, Figure 43) and are in conflict with the discard data which suggest lower mortality (mostly through the trawl fleet, Figure

43). While these data sources appear to have stronger information to inform an estimate of *M* than seen in the three-fleet model (Figure 32), the estimate of *M* obtained is biologically unreasonable for this species, where otoliths have been aged up to nine years old. As a result, the value of *M*is fixed at 0.6 in this five-fleet model, with the same fixed value used when *M* was last fixed in a School Whiting assessment (Day 2008).

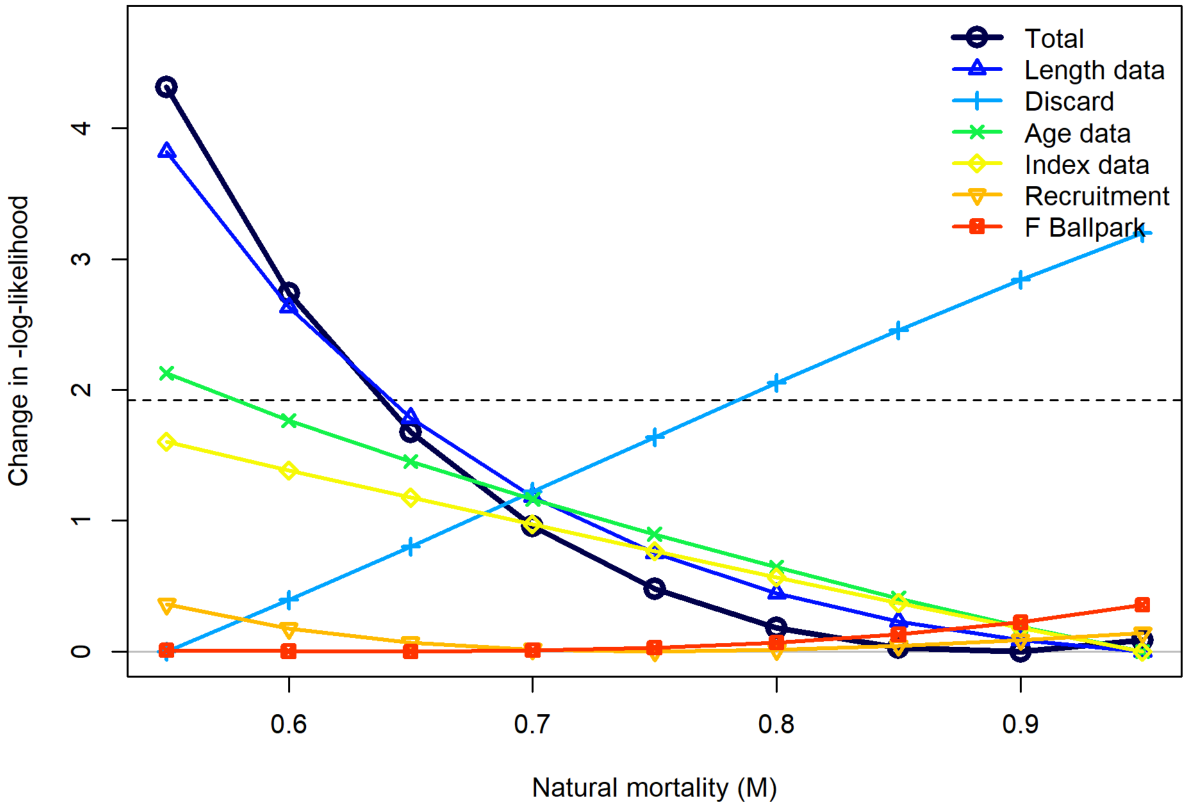


Figure 42. The likelihood profile for natural mortality for the five-fleet model, with *M* ranging from 0.55 to 0.95. The fixed value for *M* in the five-fleet model is 0.6 yr^{-1}.

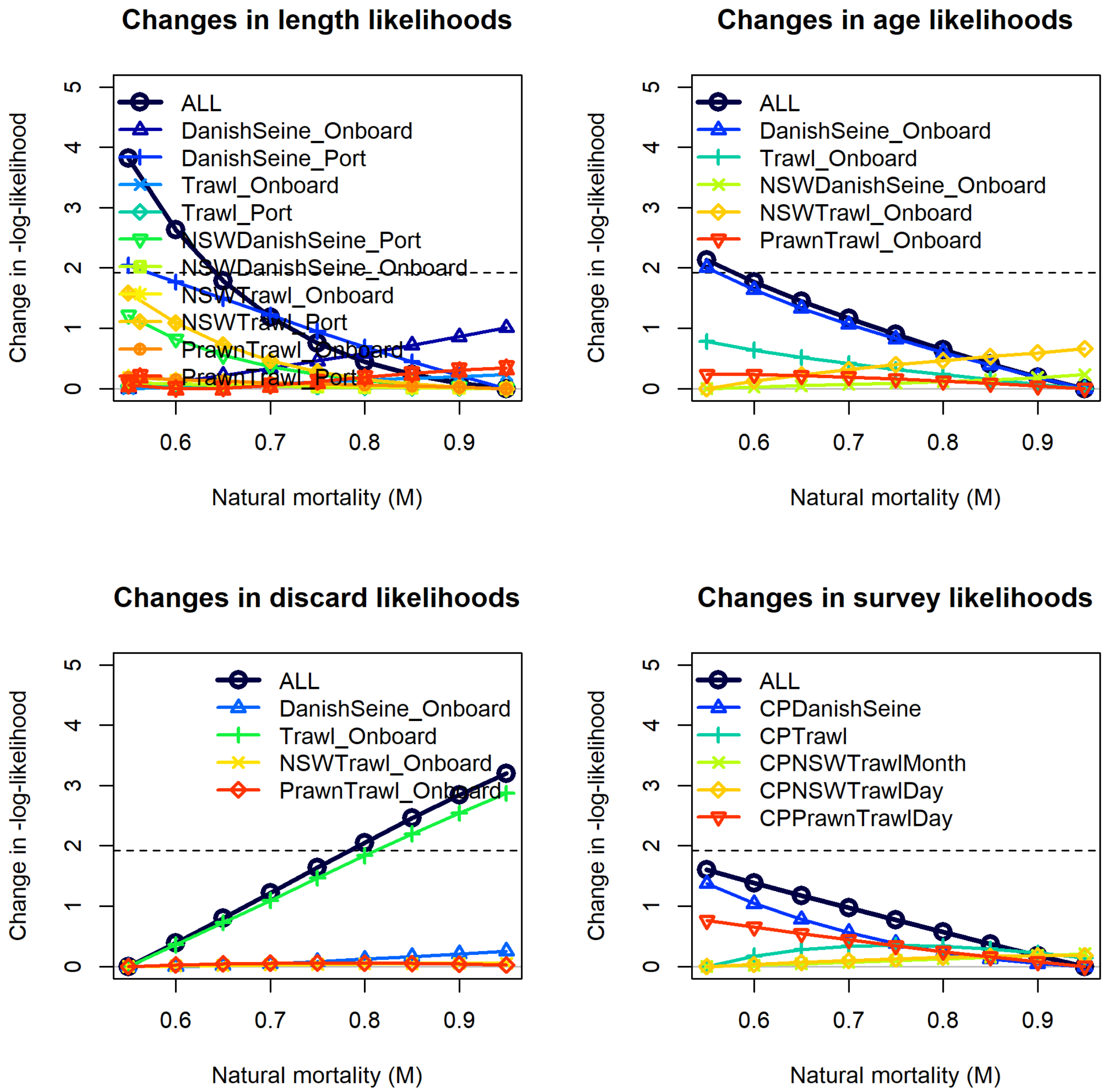


Figure 43. Piner plot for the likelihood profile for natural mortality for the five-fleet model, showing components of the change in likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

3.3.7 Five-fleet model likelihood profile: Relative spawning biomass (depletion)

For the five-fleet model for School Whiting, the likelihood profile for current spawning biomass (SSB_{2019}) relative to SSB_0 is shown in Figure 44 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests a narrower range of plausible values for depletion in 2018 than seen with the three-fleet model (Figure 40), ranging between 27% and 39% for the five-fleet model, compared to a range of 20% to 50% for the three-fleet model. The most likely value for current relative spawning biomass is around 33%.

The important data sources in providing information on relative spawning stock biomass for the five-fleet model are the length, age and discard data (Figure 44), with the length data increasing in influence and the index data decreasing, compared to the same likelihood profile for the three-fleet model (Figure 40).

The length data and age data support a higher value for relative spawning stock biomass, with the length data mainly influenced by both the trawl and NSW trawl data (Figure 45), and the age data mainly influenced by the NSW trawl data, albeit with some internal conflict from the Victorian Danish seine age data (Figure 45). The discard data is mainly influenced by the Victorian Danish seine data. While not having a big influence on the overall likelihood, the survey data has competing tension between the Victorian Danish seine CPUE series, which supports a lower value of the relative spawning biomass and the trawl and the daily NSW trawl CPUE series, both of which support a higher value for relative spawning biomass. These two competing tensions effectively cancel each other out (Figure 45, lower right panel). In contrast to these highly influential CPUE series, the remaining three CUPE series, the monthly NSW trawl CPUE series, and both of the prawn trawl CPUE series, have little influence on the likelihood profile (Figure 45, lower right panel).

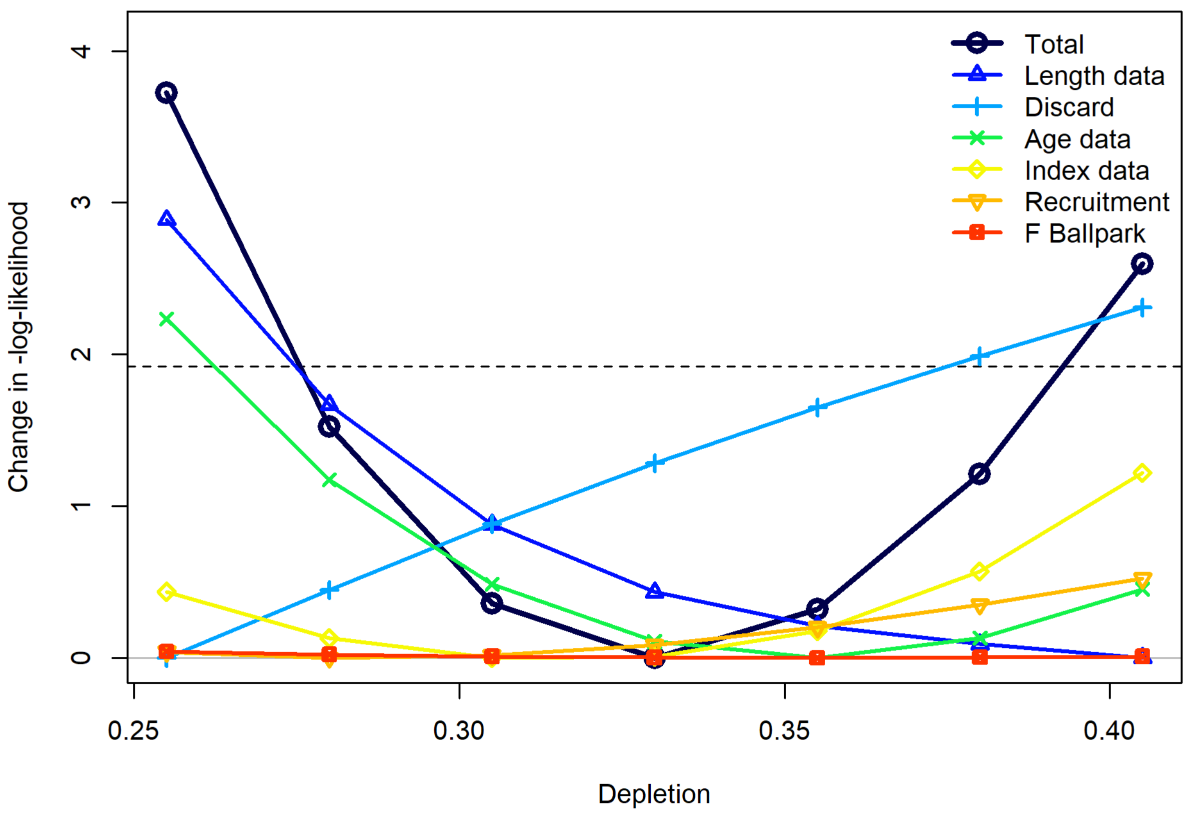


Figure 44. The likelihood profile for relative spawning stock biomass (depletion) in 2019 for the five-fleet model, ranging from about 27% to 39%. The estimated value for depletion in 2019 is 33%.

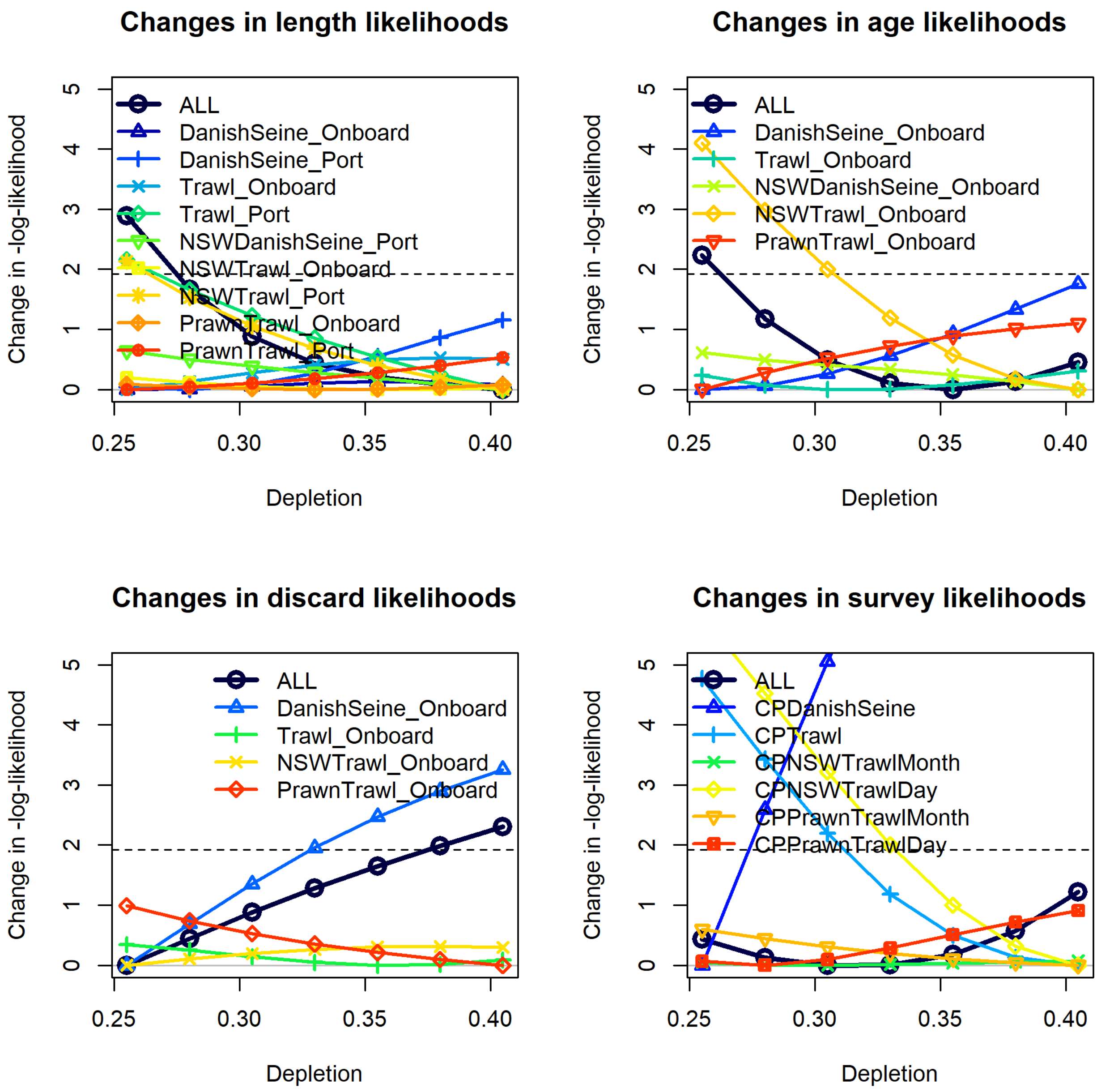


Figure 45. Piner plot for the likelihood profile for relative spawning biomass (depletion) in 2019 for the three-fleet model, showing components of the change in likelihood for length, age, discard rate estimates and surveys (CPUE) by fleet.

Likelihood profiles for steepness, unexploited spawning stock biomass and current spawning stock biomass were not constructed for the five-fleet model.

3.4 Retrospective analyses

Preliminary retrospective analyses for School Whiting were presented at the October 2020 SERAG meeting for the three-fleet model. These retrospective analyses were not repeated for the five-fleet model, but the retrospective analysis results for the three-fleet model are presented here. While these may be indicative of the expected results for the five-fleet model, ideally this analysis would be repeated on the five-fleet model. Retrospective analysis involves working backward in time and removing successive years of data from the assessment, starting from the most recent year of data. This analysis can highlight potential problems and instability in an assessment, or some patterns or features that emerge from the data.

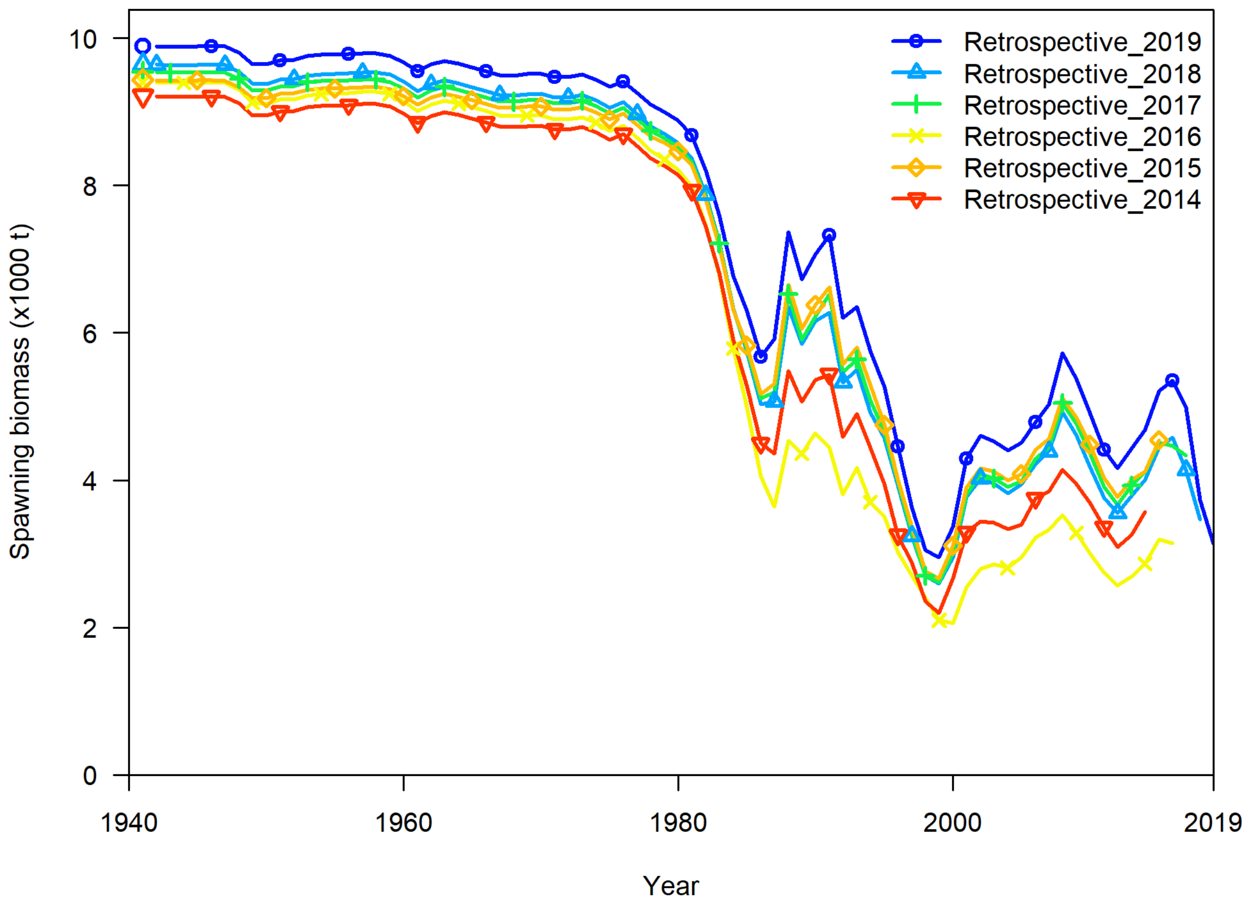


Figure 46. Retrospectives for absolute spawning biomass for School Whiting three-fleet model, with data removed back to 2018 (light blue) and then successive years removed back to 2014 (red).

A retrospective analysis for absolute spawning biomass is shown in Figure 46, with the data after 2018 removed initially (shown in light blue), then successive years of data removed back to 2014 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 47. In both cases the changes are minor with the largest change at the end of the retrospectives deleting all data after 2014 (red, translation down). Note that the retrospective to 2014 (yellow) has not converged, so the results for this retrospective should be ignored, or at best treated with caution. In general, terms, the addition of data from 2015 (orange series) produces an upwards revision to the stock status from 1990 onwards (Figure 47). Adding subsequent years of data to 2018 has limited additional impact, and then adding the last year of data (2019, blue) results in a further revision upwards to the stock status (Figure 47).

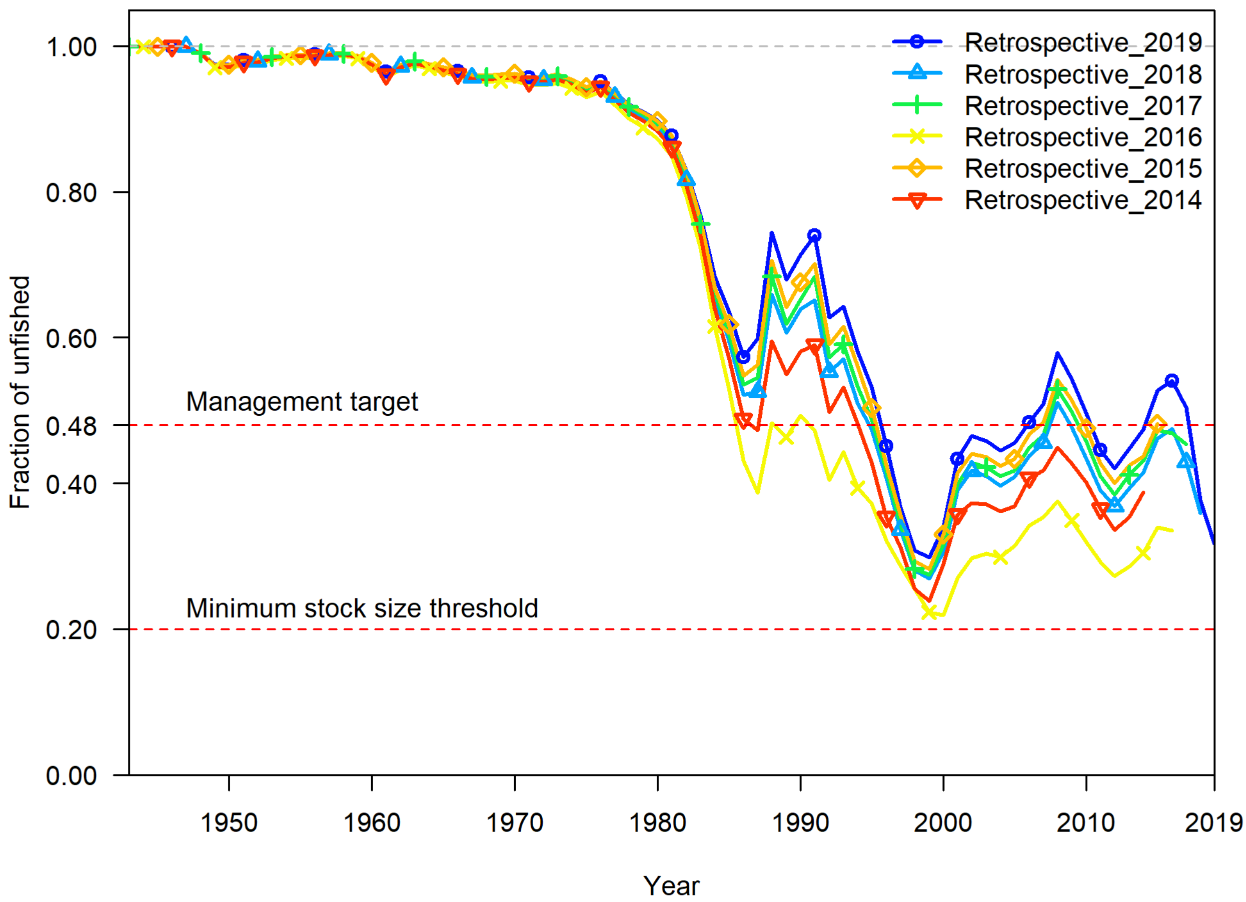


Figure 47. Retrospectives for relative spawning biomass for School Whiting three-fleet model, with data removed back to 2018 (light blue) and then successive years removed back to 2014 (red).

When this retrospective analysis is applied to the recruitment time series (Figure 48), a pattern emerges for the 2016-2018 retrospectives where the last estimated recruitment deviation is well below average. This estimate is successively revised upwards, as more data is added, and this “poor last recruitment” is transferred to the additional year where a recruitment deviation is first estimated (Figure 48).

An alternative presentation of the retrospective analysis applied to the recruitment time series is shown in a “squid plot” (Figure 49), which follows changes in the recruitment deviations for particular cohorts as the last five years of data is successively removed. Each coloured string corresponding to a cohort only includes a maximum of six points, one for the full three-fleet model and one for up to five different retrospectives. Each string can be followed from right to left as successive years of data are removed. The changes to the recruitment deviation estimates, as each year of data is removed, are measured by changes in the y-axis, with a negative value indicting a revision downwards and a positive value indicating a revision upwards, relative to the most recent estimate.

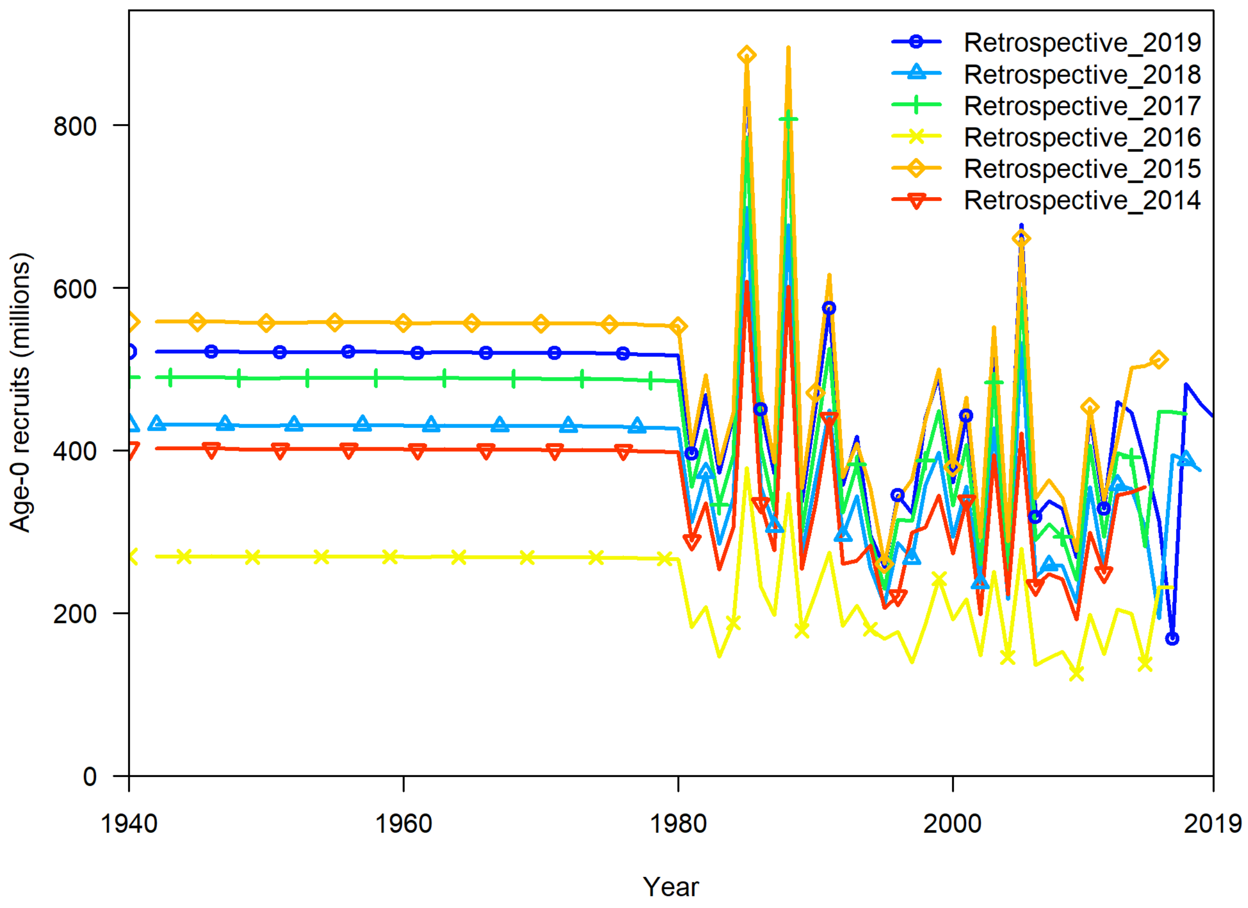


Figure 48. Retrospectives for recruitment for School Whiting three-fleet model, with data removed back to 2018 (light blue) and then successive years removed back to 2014 (red).

For cohorts spawned in years 2012-2016, the point on the far left of each string represents average recruitment, as this corresponds to a year when the recruitment deviation for this cohort cannot be estimated. Hence the corresponding y-values, for these left most points for cohorts spawned in 2012-2016, represent the magnitude of the final recruitment deviation estimated in the three-fleet model with positive y-values corresponding to negative recruitment deviations (for the three-fleet model using all data) and negative y-values corresponding to positive recruitment deviations. The variation along each string indicates how the recruitment deviation estimate changes as each year of successive data is added (moving to the right) or removed (moving to the left). Changes to estimates of deviations for the older birth years (e.g. 2006 and 2007) are smaller than more recent birth years, as there is little additional information on the size of these cohorts from data obtained in the period 2014-2019. These cohort birth years are largely flat on the right-hand side of this “squid plot”, although three appear to be some bumps (red and orange series, 2006 and 2007, Figure 49), possibly associated with the non-convergent 2016 retrospective.

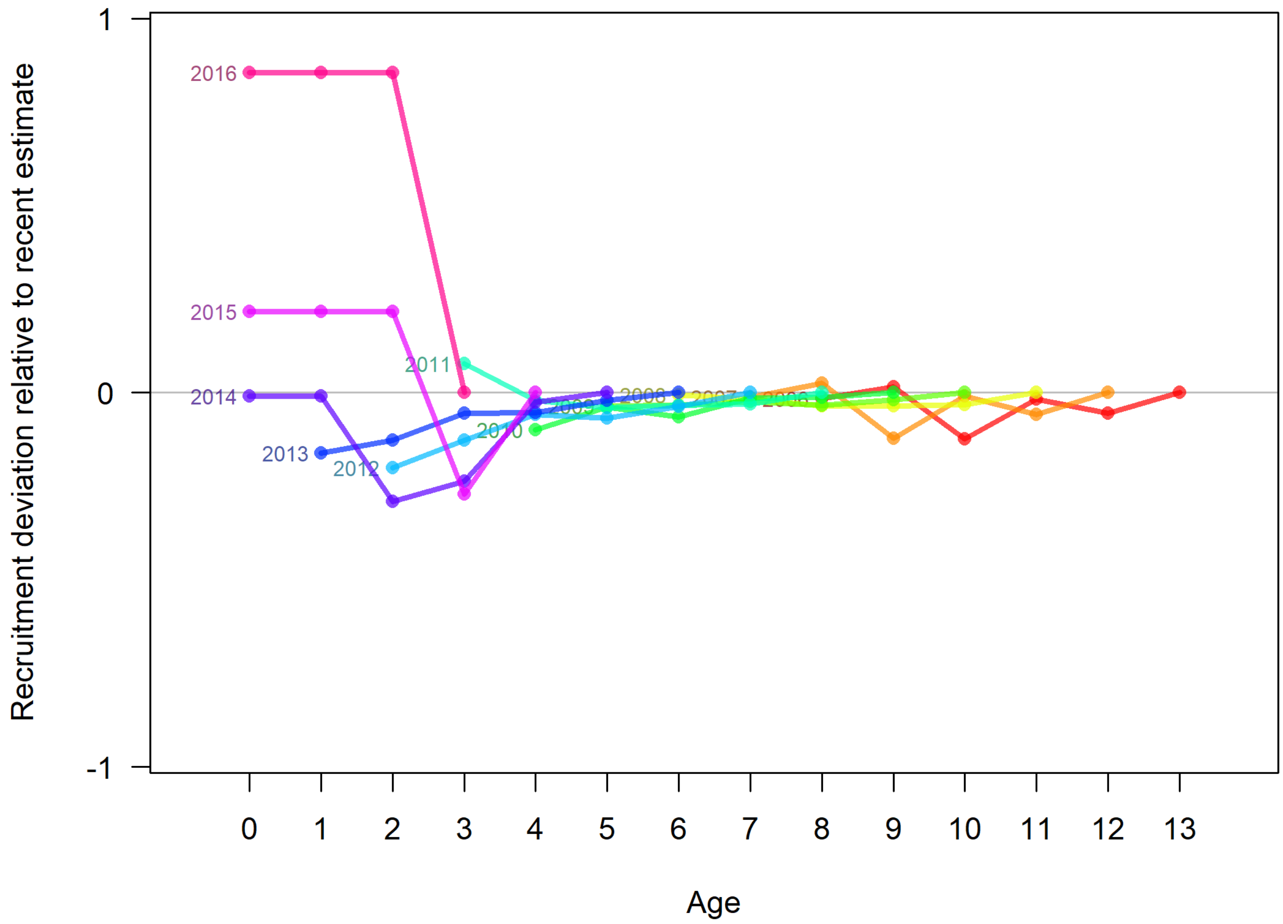


Figure 49. Retrospective analysis of recruitment deviations (squid plot) for School Whiting three-fleet model, with data removed in successive years back to 2014.

The pattern for the 2016-2018 retrospectives where the last estimated recruitment deviation is well below average and subsequently revised seen in Figure 48 can also be seen in the squid plot for the 2014-2016 cohorts (Figure 49, pink and purple colours), which all feature a sharp drop in the y-axis, the year after the recruitment is first estimated. Follow the cohort from left to right and observe a sharp drop, corresponding to an upward revision of the recruitment deviation, for all three cohorts, immediately after the flat section, which corresponds to the second year that recruitment is estimated. If there was no retrospective pattern apparent, we would not expect to see consistent changes which, in this case, are all in the same direction, and all in the second year that the recruitment is estimated.

Examples of pathological patterns in a squid plot would include a one-sided plot where all the adjustments to recent recruitment events were in the same direction (e.g. all positive or all negative), indicating a trend that may warrant further exploration and may indicate some model mis-specification. There is evidence of this pattern here, for the last three years.

While these retrospective analyses do reveal some retrospective patterns, or apparent biases in the estimates at the end of the time series due to the addition of new data, it is worth noting that the five-fleet model does not feature such a low recruitment deviation at the end of the series. A retrospective analysis has not been completed for the five-fleet model, and until that analysis is performed, it is impossible to draw definitive conclusions about whether the retrospective pattern seen in the three-fleet model also appears in the five-fleet model.

Fits to the Danish seine and trawl CPUE series for these retrospective analyses show the model fitting each additional point at the end of the Victorian Danish seine series (Figure 50) as additional years are added. In contrast, adding additional years of data, including additional trawl CPUE points, does not result in better fits to the trawl series (Figure 51). This reflects the fact that the three-fleet model achieved better likelihood fits but preferentially fitting to the Victorian Danish seine CPUE rather than the trawl CPUE. There are no retrospective patterns of concern in the fits to the CPUE series (Figure 50 and Figure 51).

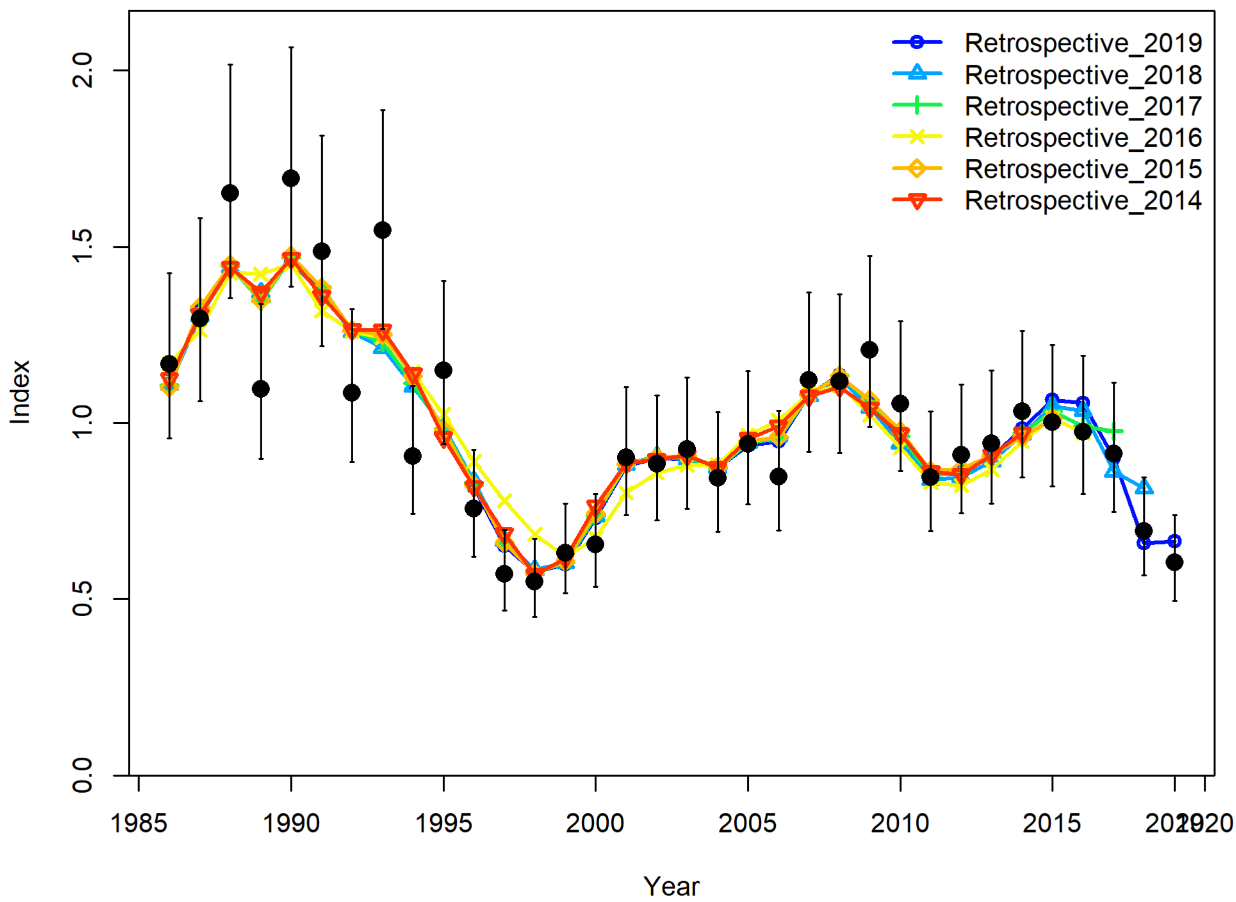


Figure 50. Retrospectives for the Victorian Danish seine CPUE fits for School Whiting three-fleet model, with data removed back to 2018 (light blue) and then successive years removed back to 2014 (red).

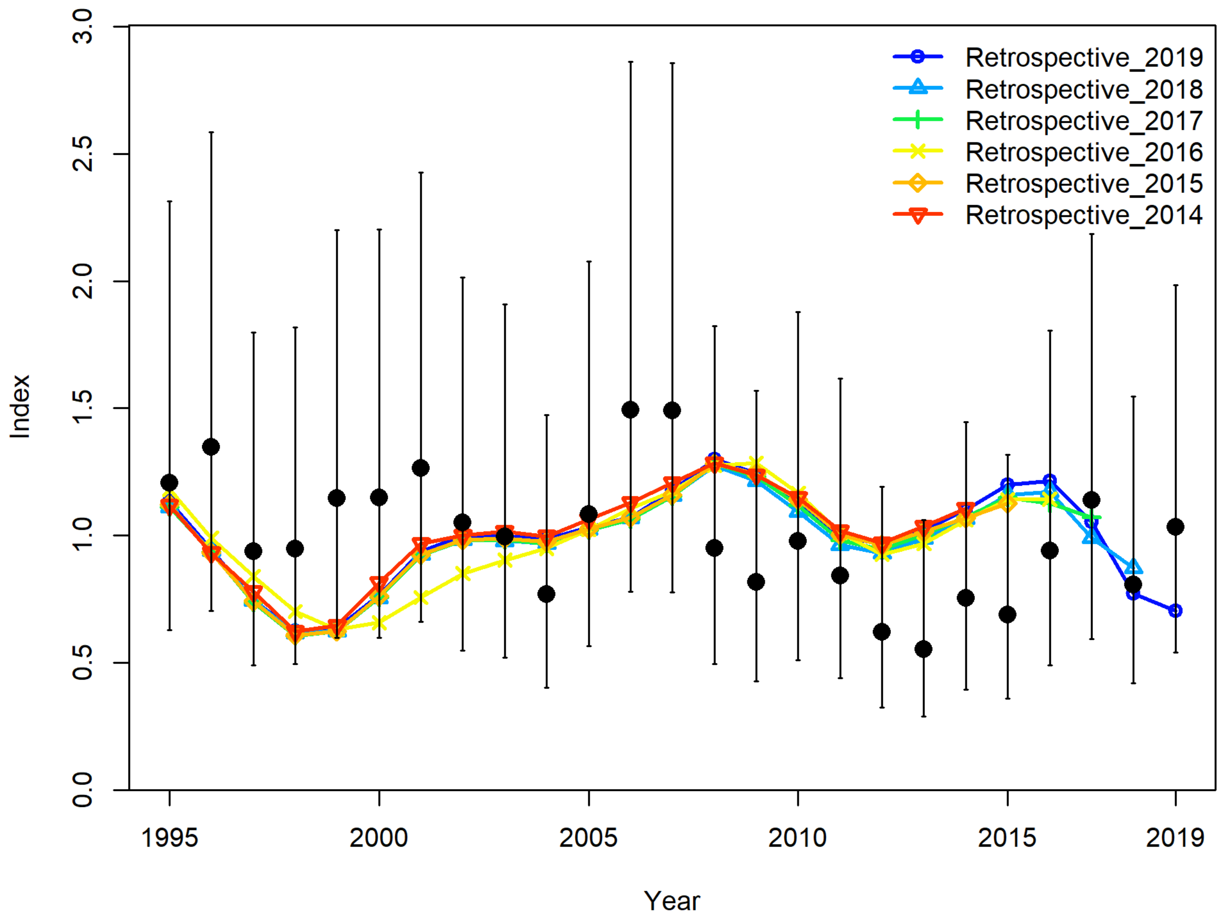


Figure 51. Retrospectives for the trawl CPUE fits for School Whiting three-fleet model, with data removed back to 2018 (light blue) and then successive years removed back to 2014 (red).

3.5 Jitter analyses

Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, initially a check on whether a better "optimal solution" may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or "jittered", simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 25 replications for both the three-fleet and the five-fleet model.

For the three-fleet model, 15 of the 25 jitter replicates found the same optimal solution, with negative log likelihood of 151.924. The remaining ten replicates found different (worse) "optimal" solutions, with a negative log likelihood of 178 for the next closest value, with the remaining eight producing "optimal" negative log likelihoods, which need to be minimised in order to maximise the likelihood, ranging from 1,715 up to 2,052,100.

For the five-fleet model, 9 of the 25 jitter replicates found the same optimal solution, with negative log likelihood of 358.314. The remaining 16 replicates found different (worse) “optimal” solution, three with negative log likelihoods ranging from 362 to 405, with the remaining 13 producing “optimal” negative log likelihood, which need to be minimised to maximise the likelihood, ranging from 8,877 up toto 4,237,310.

These results give confidence that the solutions found with the chosen parameter starting values for both the three-fleet and the five-fleet model are the optimal solutions.

3.6 Low recruitment scenario

The pattern in estimated recruitment deviations (Figure 27) indicate a seven-year run of average or below average recruitment from 2006-2012. Low recruitment projections are used for a number of species in the SESSF, with forward projections to the end of a proposed three-year multi-year TAC period. Low recruitment projections are achieved by setting those most recent recruitment deviations which are not informed by data, and hence not estimated in the model, equal to the mean of the last five or 10 estimated recruitment deviations, rather than fixing these deviations at zero (or average recruitment). Future recruitment deviations are also set at the same low recruitment value, rather than at average recruitment, which use absolute recruitment estimates projected from the stock-recruitment curve. The mean of the last five estimated recruitment deviations (2012-2016) is -0.0167 and for the last 10 estimated recruitment deviations (2007-2016) is -0.14214. Low recruitment projections allow examination of the impact of a potential productivity shift on the stock between now and the time the next stock assessment is scheduled. Given the five-year mean recruitment deviation is very close to zero, low recruitment projections were only considered for the 10-year mean recruitment deviation (-0.14214), and compared to the five-fleet base case for School Whiting, assuming projected catches from 2021 are set equal to the RBC, calculated for the particular scenario considered (Table 17). Note that the RBC calculated for the low recruitment scenario (column 3 of Table 17) is calculated assuming all future recruitment, beyond the RBC calculation, will be average recruitment (i.e. the RBC calculation assumes that all future recruitment will be taken directly from the stock recruitment curve, and not low recruitment). This RBC setting for the low recruitment scenario does not account for the assumed low recruitment projected to 2023.

The relative spawning biomass is shown for base case and the low recruitment scenario in Figure 52, using the recruitment deviations shown in Figure 53. Note that the relative spawning stock status declines in 2023 and 2024, as the impacts of seven years of poor recruitment are felt, assuming that the full RBC is caught for each projected year, and before the return of average recruitment, which is assumed from 2024 onwards, has had time to enter the spawning biomass and to contribute to rebuilding of the stock.

The projections under fixed average recruitment, assuming that the full RBC is caught for each projected year, result in the spawning stock status exceeding 47% by 2026. Under the low recruitment scenario, with fixed low recruitment from 2017-2023 and average recruitment from 2024 onwards, the spawning stock biomass is not projected to exceed 47% until 2040.

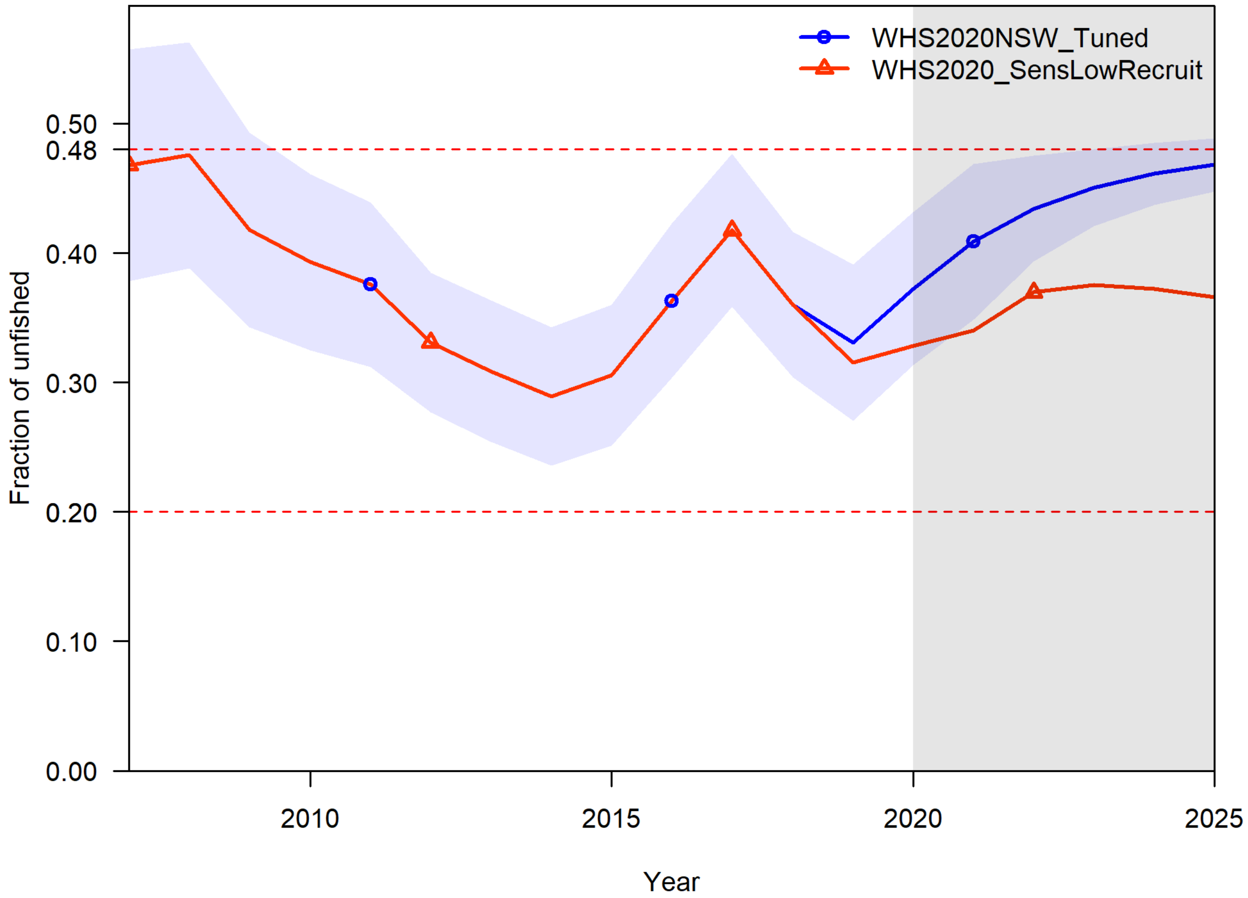


Figure 52. Projected relative spawning biomass (2007-2025) for the five-fleet base case (blue, average recruitment) and the low recruitment scenario (red, low recruitment).

Table 17. Summary of projected total catch (landed catch plus model estimated discards) under the average recruitment and low recruitment scenarios.

	Total catch (landings + estimated discards)	
Year	Average recruitment	Low recruitment
2020	2140	2136
2021	2140	1697
2022	2250	2019
2023	2321	2175
2024	2368	2287
2025	2398	2382

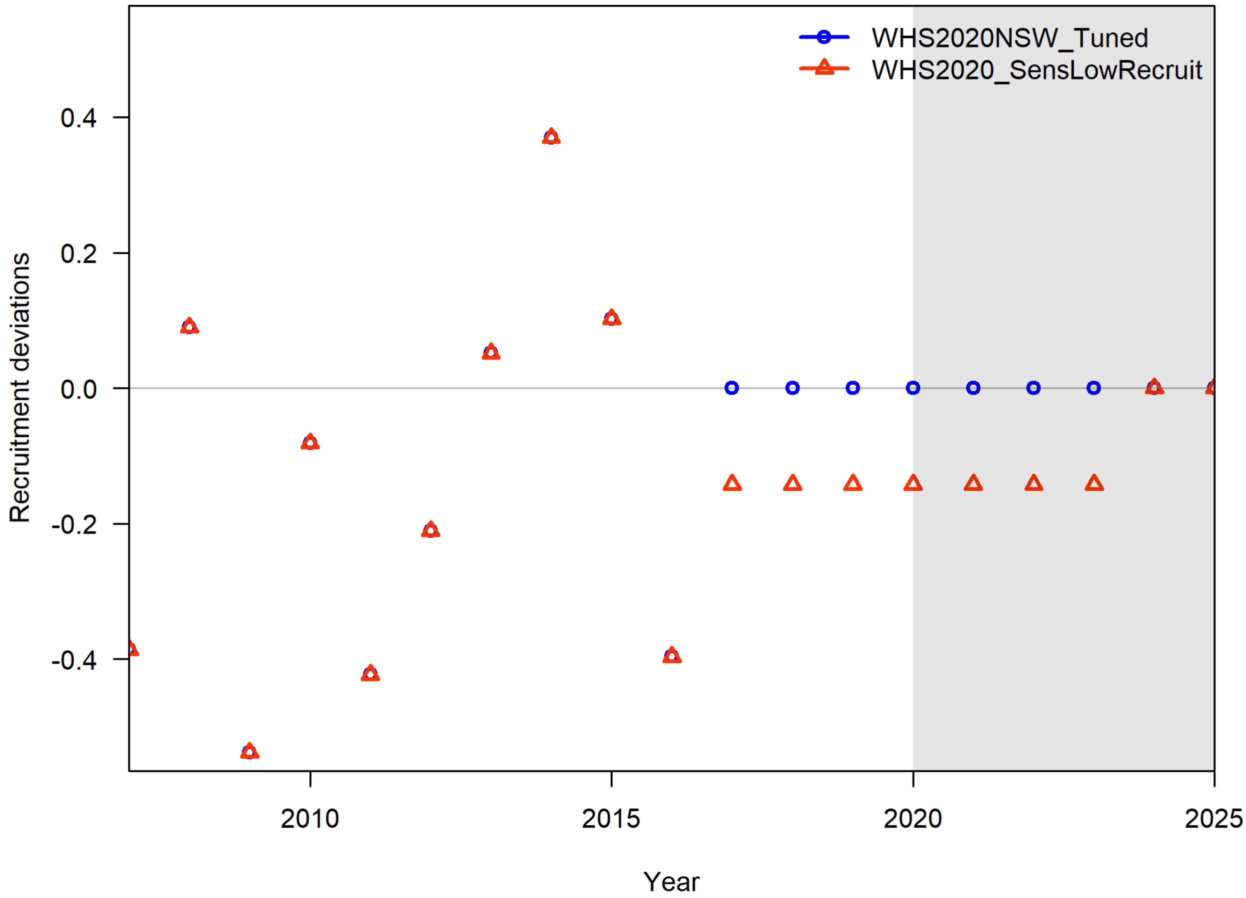


Figure 53. Recruitment deviations used for the five-fleet base case and the low recruitment projections (2007-2025). Recruitment deviations are estimated up until 2016 (for both scenarios) and are fixed (at zero) from 2017 onwards for the base case (blue, average recruitment)and fixed at -0.14214 from 2017-2023 for the low recruitment scenario (red), before returning to zero from 2024 onwards.

3.7 Sensitivity tests and alternative models

Results of the sensitivity tests to spawning stock status are shown in Table 18. Both the total likelihood and individual unweighted likelihood components for each of the CPUE, discard, length, age and recruitment estimates for the five-fleet base case are shown in the first row of Table 19. Differences in likelihood between the base case and each of the 25 sensitivities are also shown in Table 19, with differences shown in both the total likelihood and in the individual unweighted likelihood components for each of CPUE, discard, length, age and recruitment. The likelihood reported is the negative log likelihoods, so negative values in differences from the base case indicate a better fit (greater likelihood) and positive values indicate a worse fit.

Some sensitivities were unable to be completed (doubling the weight on length, *M* =0.7) with the models, which were not re-tuned, failing to converge in these cases. Alternative sensitivities were conducted, with alternative values selected for the respective parameters to achieve model convergence.

Compared to the sensitivity analysis results presented in the 2017 assessment (Day 2017), results shown here are more sensitive to the assumed values for steepness, *h*, with a 7% range in spawning stock status over the values examined (Table 18), compared to 2% range in 2017 (Day 2017), and less sensitive to doubling and halving the weight on CPUE, with a 1% range in spawning stock status (Table 18) compared to 6% in 2017 (Day 2017). There was a similar sensitivity range for all other common sensitivities examined in both 2020 and 2017. A sensitivity to the fixed value of natural mortality, *M,* was previously examined, when *M* was last fixed in the model, in 2008 (Day 2008) and, as in 2008, spawning stock status is quite sensitive to the assumed value for *M*. While the likelihood profiles for *M* and *h* provide useful information on the changes in likelihood and improvements in the fits to the models, this sensitivity analysis also examines the consequences of different values for these parameters on the spawning stock status estimates. While there may not be clear indications of improvements to the model fit, from the likelihood profiles, changes to these fixed parameters do have an impact on the estimates of spawning stock status (Table 18). This impact is somewhat larger than may be expected from the likelihood profile analysis alone, with a range of 37%-44% for the values of *h* considered and 31%-57% for the values of *M* considered, indicating the value of conducting both a likelihood profile and a separate sensitivity analysis.

Table 18. Summary of results for spawning stock biomass for the base-case and sensitivity tests.

Case		SSB_0	SSB_{2021}	SSB_{2021}/SSB_0
0	base case five-fleet	10,780	4,407	0.41
1	h 0.65	11,731	4,354	0.37
2	h 0.85	10,176	4,447	0.44
3	M 0.5	11,759	3,593	0.31
4	M 0.75	11,088	6,290	0.57
5	50% maturity at 14cm	13,349	6,637	0.50
6	50% maturity at 18cm	7,650	2,481	0.32
7	σ_R = 0.6	10,196	4,158	0.41
8	σ_R = 0.8	11,515	4,715	0.41
9	wt x 2 length comp	10,516	4,415	0.42
10	wt x 0.75 length comp	10,909	4,455	0.41
11	wt x 2 age comp	10,944	4,537	0.41
12	wt x 0.5 age comp	10,612	4,278	0.40
13	wt x 2 CPUE	10,768	4,541	0.42
14	wt x 0.5 CPUE	10,696	4,437	0.41
15	exclude Vic DS CPUE	10,640	4,682	0.44
16	exclude trawl CPUE	10,544	4,071	0.39
17	exclude NSW trawl CPUE	10,627	4,010	0.38
18	exclude prawn trawl CPUE	10,827	4,483	0.41
19	exclude Vic DS + TW CPUE	10,227	4,605	0.45
20	exclude NSW CPUE	10,604	3,976	0.37
21	only Vic DS CPUE	10,319	3,597	0.35
22	only trawl CPUE	10,895	4,956	0.45
23	only NSW trawl CPUE	10,260	4,656	0.45
24	only prawn trawl CPUE	10,328	4,516	0.44
25	three-fleet model	9,895	4,440	0.45

Sensitivity of spawning stock status to the assumed age at 50% maturity continues to be relatively high, as shown in previous assessments (Day 2007, Day, 2008, Day, 2009, Day 2017). School Whiting become sexually mature at two years of age (Smith and Wayte, 2005), which corresponds to a length of around 16 cm. Three-year old fish are about 18 cm long and School Whiting reach 14 cm 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 15 cm in northern NSW (Kevin Rowling, pers comm. based on an unpublished research by Grey and Barnes) and 17 cm 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 16 cm, but hopefully updated biological information to inform this parameter will be available before the next assessment is conducted.

This assessment is not sensitive to the weighting placed on the length or age compositions or the CPUE series with the spawning stock status ranging from 40% to 42% for all of these cases (Table 18) and the overall likelihood deteriorating in all cases (Table 19). The length and age data weightings were set according to best practice in SESSF stock assessments, using iterative reweighting of this data to match input and output effective sample sizes and the CPUE series were tuned by estimating additional standard error within Stock Synthesis, so there is no strong argument to consider alternative weighting scenarios for the length, age or CPUE data.

Sensitivities 15-24 all examine the impact of excluding one or more CPUE fleet, with sensitivities 21-24 only incorporating CPUE data from a single fleet. Spawning stock status ranges from 35% (Sensitivity 21, only including Victorian Danish seine CPUE series, Table 18) to 45% (Sensitivities 19, 22, and 23, all excluding the Victorian Danish seine CPUE series, Table 18). While there is no suggestion that various CPUE series should be excluded from the base case, these sensitivities give some indication of the influence of the CPUE from different fleets. Sensitivity 19 only includes CPUE series from the Commonwealth data (Victorian Danish seine and trawl) and Sensitivity 20 only includes NSW CPUE series (NSW trawl and prawn trawl). The general conclusion from these sensitivities is that the Victorian Danish seine fleet CPUE series tends to support lower spawning stock status than the CPUE series from the other three fleets, and that the trawl and NSW trawl fleet CPUE series support slightly higher spawning stock status than the prawn trawl fleet CPUE series.

The three-fleet model (S25) produces a lower estimate of SSB_0 than the five-fleet model, but estimates a similar value for SSB_{2021} resulting in a higher estimate of spawning stock status in 2021 for the three-fleet model then the five-fleet model (45% compared to 41%, Table 18).

Unweighted likelihood components for the base case and differences for the sensitivities (Table 19) indicate where model fits improve or deteriorate and which data components contribute to these changes. The overall likelihood is only improved significantly for the sensitivities with high M (S4) and low σ_R (S7), with non-significant improvements for high h (S2) and 50% maturity at 14cm (S5) (Table 19). Changes of negative log likelihood of more than 1.92 units, suggest a model that has a statistically significant improvement in fit, but such comparisons should only be made between alternative models with the same model structure, the same parameters being estimated and without altering the weighting of likelihood components. Differences indicated in grey in Table 19 are indicative only.

3.8 Additional requests

3.8.1 Future work list from the 2017 assessment

In the 2017 assessment (Day 2017), there were a number of suggestions for future work. While there is no new information available on stock structure, a project has commenced exploring this issue, which hopefully can feed into the next School Whiting assessment. Issues identified with the 2010 Danish seine age data have been resolved and this year of length frequency data is now included in the assessment. A large quantity of previously unavailable NSW state data has been made available for this stock assessment, including updated catch series, discarding rates, length and age composition data and catch rate data allowing the development of a new five-fleet model. While a likelihood profile on R_0 has not been produced, more relevant likelihood profiles have been produced for M, h, SSB_0, current SSB and current spawning stock status. Retrospective analyses have also been performed, at least on the three-fleet model.

3.8.2 Tony Smith review 2020

Tony Smith conducted a review of the 2017 assessment delivered to SESSFRAG in August 2020 with a number of recommendations.

Re-weighting different CPUE series and removing data series

Tony Smith's review of the 2017 School Whiting assessment suggested exploring the impacts of increasing or decreasing weights for the different CPUE time series. While this was explored by setting some of these weights to zero (Sensitivities 15-24, Table 18 and Table 19), further exploration could be done, using weightings other than just one and zero. Likewise, this review suggested exploring the impact of removing entire data series (e.g. all trawl length data or all prawn trawl age data). This opens up a myriad of possibilities, so if this was to be explored, carefully targeting of the possibilities would be required.

Likelihood reported by component

Tony Smith's review of the 2017 School Whiting assessment suggested reporting likelihood components by fleet. These are now reported in Table 13.

Uncertainty in catch series

Tony Smith's review of the 2017 School Whiting assessment suggested accounting for catch uncertainty in some way, with the compilation of alternative catch scenarios. While there is some catch uncertainty, this issue has been partly addressed through revisions to the catch history, especially the NSW state catches. Alternative catch series could be explored in future, but this would require RAG agreement on the scenarios to be explored.

Stacked plot of biomass catch and recruitment

The stacked plot of biomass, catch and recruitment requested in Tony Smith's review of the 2017 School Whiting assessment in included in (Figure 31).

3.9 Future work

3.9.1 Stock structure

Further genetic studies and other biological studies designed to inform stock structure for School Whiting would be very useful. An FRDC funded project has commenced to investigate these very questions. If this work produces clear results recommending geographical separation of stocks, issues relating to separation of the data input to the assessment to match any new stock structure will need to be addressed. Sensitivities looking at stock structure were considered for this assessment. Splitting the stock at the Barrenjoey line, as was done by Day (2017) is relatively straightforward, given the structure of the fleets used in this five-fleet model. However, SERAG requested that this sensitivity not be repeated in 2020. An alternative split in stock at the NSW Victorian border was requested by SERAG in 2020, if possible, but the data processing and model restructuring requirements that this imposed made it impossible to complete this sensitivity for this assessment. This should be possible for a future assessment, although it may be prudent to await the results of the current School Whiting FRDC funded stock structure project.

3.9.2 2018 trawl onboard length data

The 2019 trawl onboard length data has an unusual spike with over 60% of the samples apparently in the largest size class. This appears to be a data processing or data entry issue. Investigation of this issue and appropriate modification of this length frequency sample will enable this year of length frequency data to be included in a future assessment. This will hopefully be a straightforward addition to the next stock assessment.

3.9.3 Processing of NSW length and age data

The Commonwealth length and age data is automatically processed from a common database covering ISMP and age data for a number of SESSF species. This reduces the chance of processing errors. There was neither sufficient time nor resources to pre-process and run the NSW data through this same processing software in 2020. While considerable care was taken to process this data appropriately, it would be more reliable to process all the data using the same protocols in future.

3.9.4 Additional NSW data

The incorporation of a large quantity of NSW state data (CPUE, catch, discard, length, age) was a significant achievement in this assessment, with some length sample sizes being particularly significant, both in the 1980s and in the last 10 years. Continued collection and use of NSW state data would help inform this assessment, especially additional conditional age-at-length data for the NSW trawl and NSW Danish seine fleets (both of which only have two years of data). Given the impact of the discard rates for NSW fleets, additional estimates of discard proportions would also be very useful. Continuation of the standardisation of NSW CPUE data (NSW trawl and prawn trawl) would also be useful.

3.9.5 Retrospective analyses

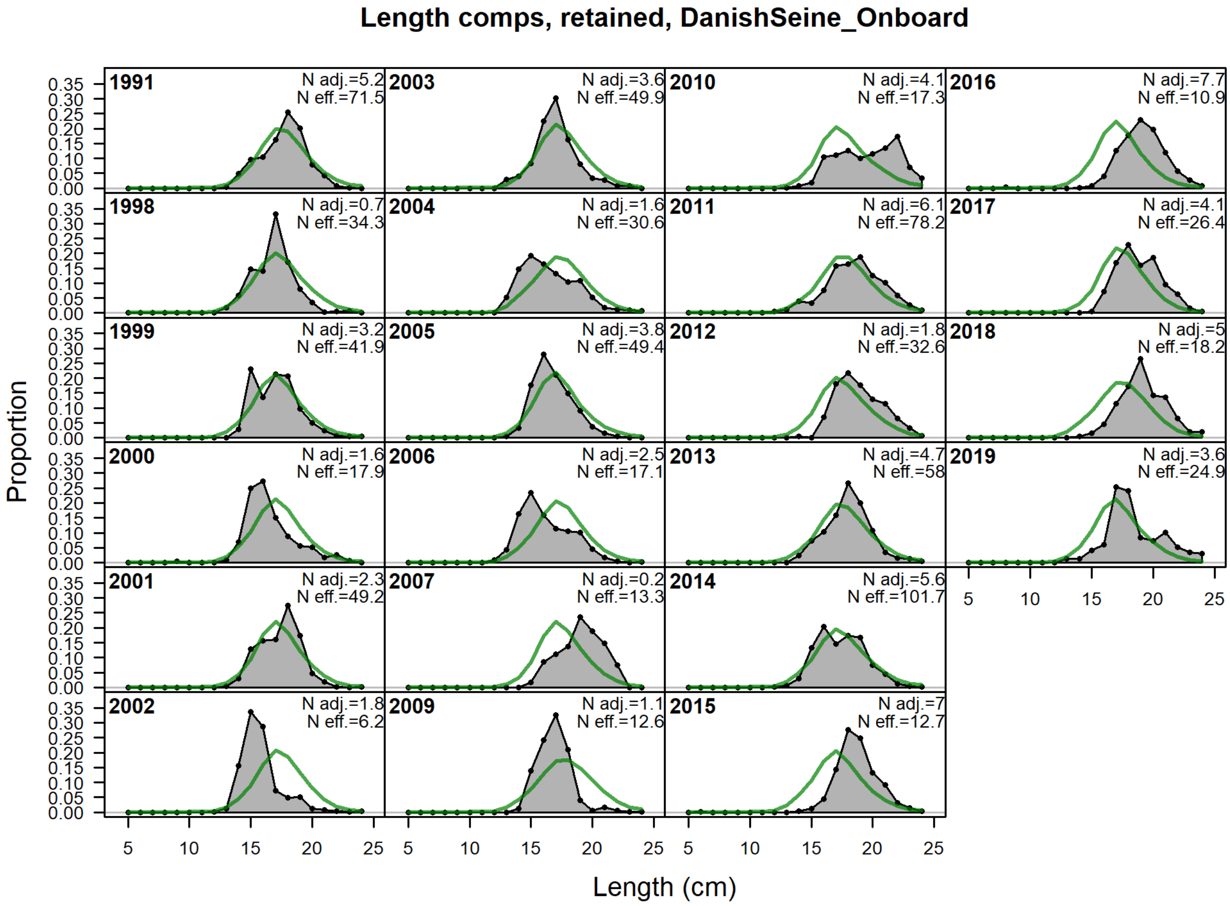
Retrospective analyses on the final five-fleet base case would be useful.

Table 19. 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. Values in grey should not be compared with the base case, due to differences in model structure or weighting of likelihood components, meaning that a statistical comparison with the base case model is not valid.

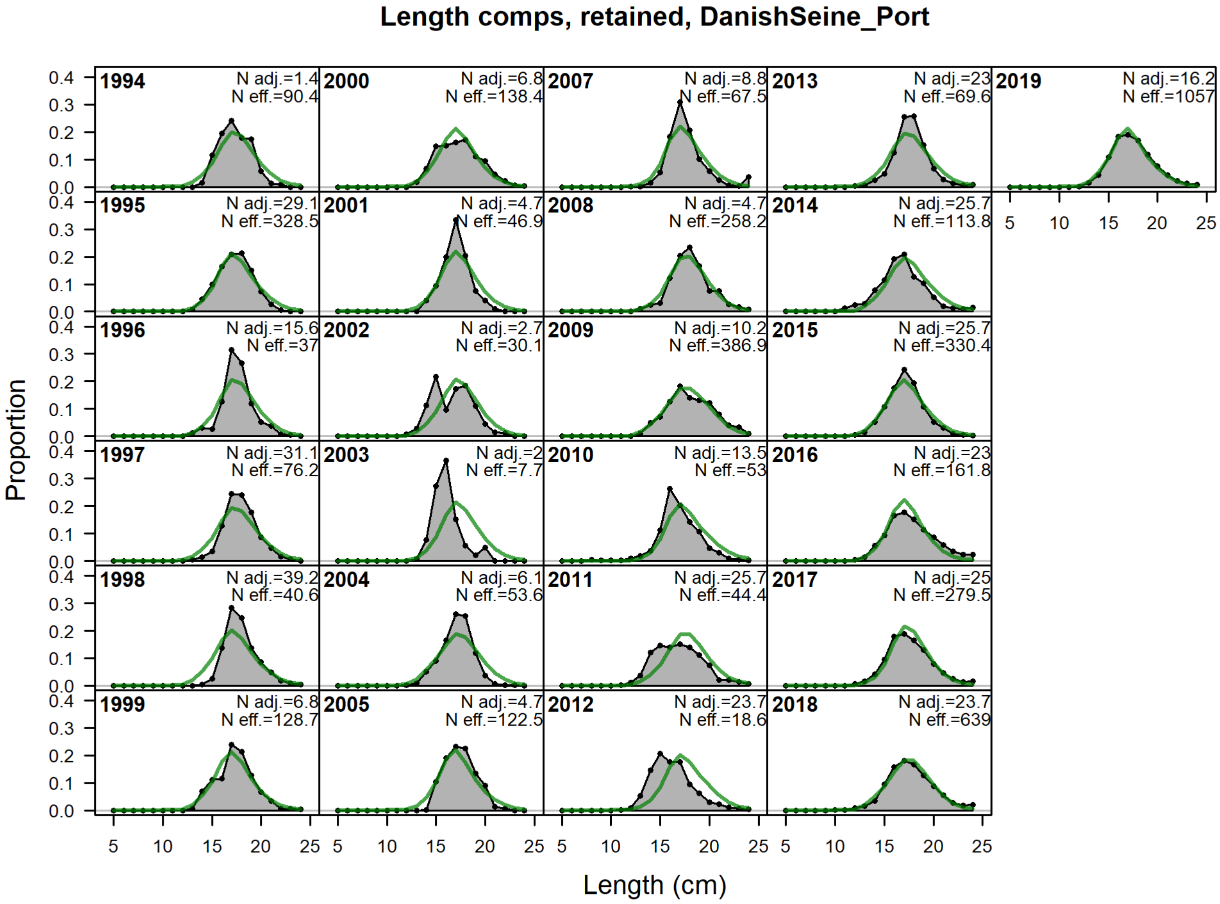
Case		Likelihood					
		TOTAL	Survey	Discard	Length comp	Age comp	Recruitment
0	base case five-fleet	358.31	-116.77	36.18	186.57	259.76	-7.44
1	*h* 0.65	0.64	-0.17	0.10	0.48	0.04	0.19
2	*h* 0.85	-0.37	0.14	-0.07	-0.33	-0.02	-0.09
3	*M* 0.5	3.86	0.46	-0.76	2.86	0.78	0.50
4	*M* 0.75	-2.21	-0.61	1.25	-1.87	-0.83	-0.17
5	50% maturity at 14cm	-0.24	0.08	-0.05	-0.20	0.00	-0.07
6	50% maturity at 18cm	6.41	0.52	1.41	3.07	1.03	0.12
7	$\sigma_R = 0.6$	-4.75	-0.01	-0.04	-0.76	0.16	-4.10
8	$\sigma_R = 0.8$	4.85	0.06	0.05	1.08	-0.11	3.77
9	wt x 2 length comp	3.48	3.65	3.31	-7.80	3.16	1.16
10	wt x 0.75 length comp	0.45	-0.56	-1.30	3.38	-0.81	-0.26
11	wt x 2 age comp	1.42	0.65	0.93	2.91	-3.25	0.18
12	wt x 0.5 age comp	1.03	-0.24	-0.58	-1.75	3.63	-0.02
13	wt x 2 CPUE	3.74	-6.05	1.93	5.50	1.77	0.58
14	wt x 0.5 CPUE	1.34	4.55	-1.34	-1.62	-0.15	-0.11
15	exclude Vic DS CPUE	31.60	28.51	-0.26	2.48	0.25	0.61
16	exclude trawl CPUE	19.67	18.31	-0.77	0.49	1.51	0.10
17	exclude NSW trawl CPUE	26.58	25.52	-1.71	0.86	1.83	0.09
18	exclude prawn trawl CPUE	20.64	21.50	-1.70	0.79	-0.04	0.09
19	exclude Vic DS + TW CPUE	58.17	57.08	0.12	0.28	0.44	0.24
20	exclude NSW CPUE	46.25	45.49	-3.67	1.72	2.38	0.31
21	only Vic DS CPUE	62.82	57.47	-3.79	3.68	4.55	0.86
22	only trawl CPUE	77.00	76.46	-2.00	0.84	1.22	0.43
23	only NSW trawl CPUE	79.27	78.55	-2.58	2.17	0.70	0.40
24	only prawn trawl CPUE	88.59	91.27	3.31	-6.32	0.58	-0.26
25	Three-fleet model	-206.39	41.05	7.04	-80.86	-173.73	0.09

Appendix A

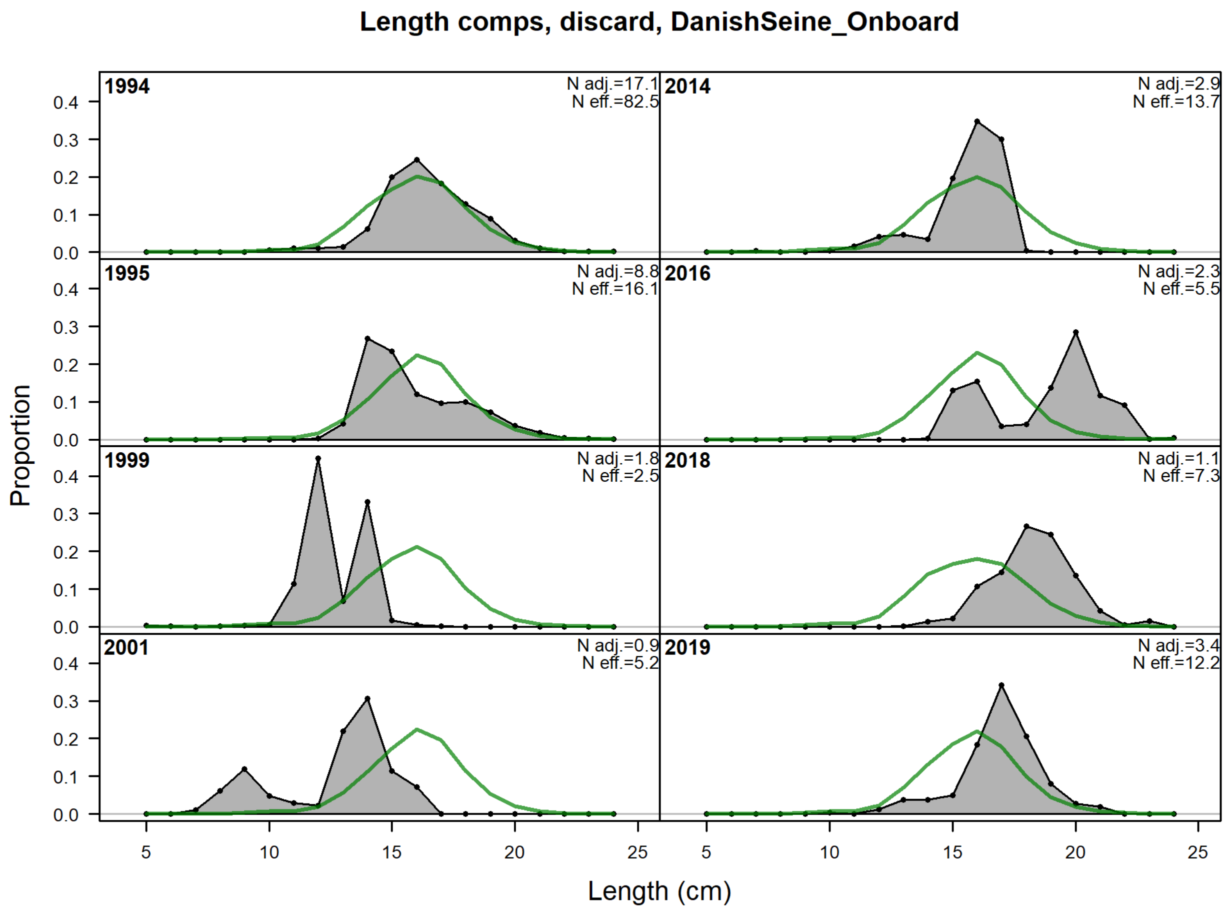
A.1 Fits to length composition, implied fits to age composition, and diagnostics for fits to conditional age-at-length data.



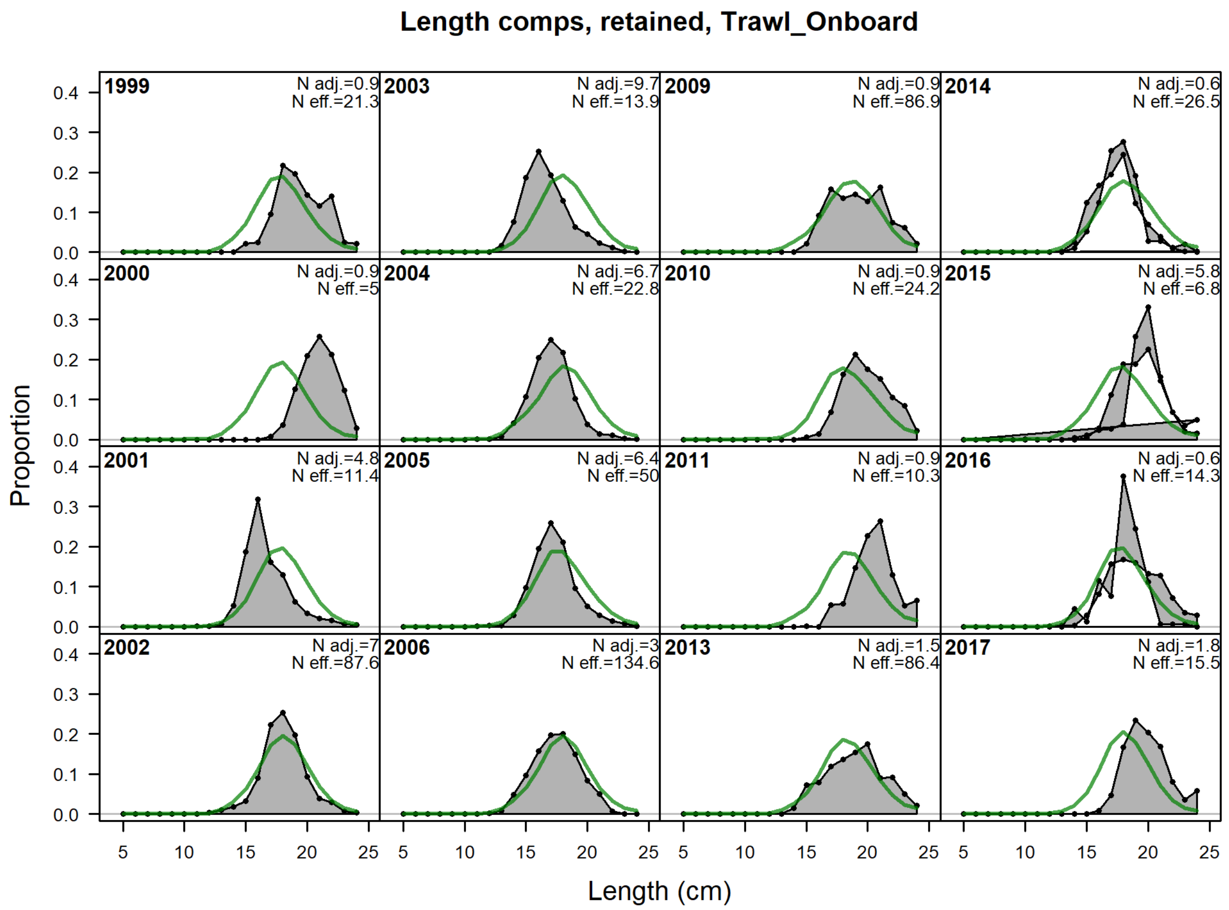
Apx Figure A.1 School Whiting length composition fits: Danish seine onboard retained.



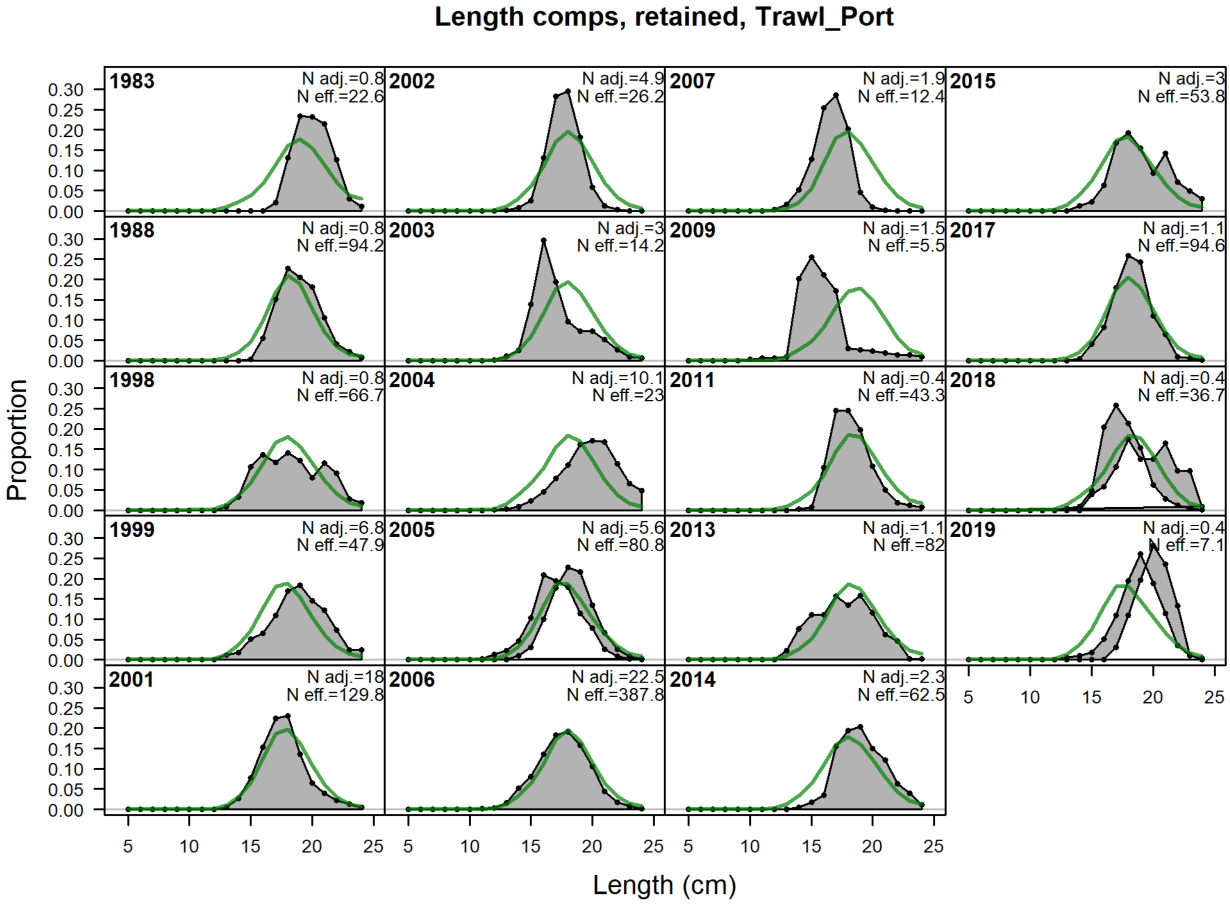
Apx Figure A.2 School Whiting length composition fits: Danish seine port retained.



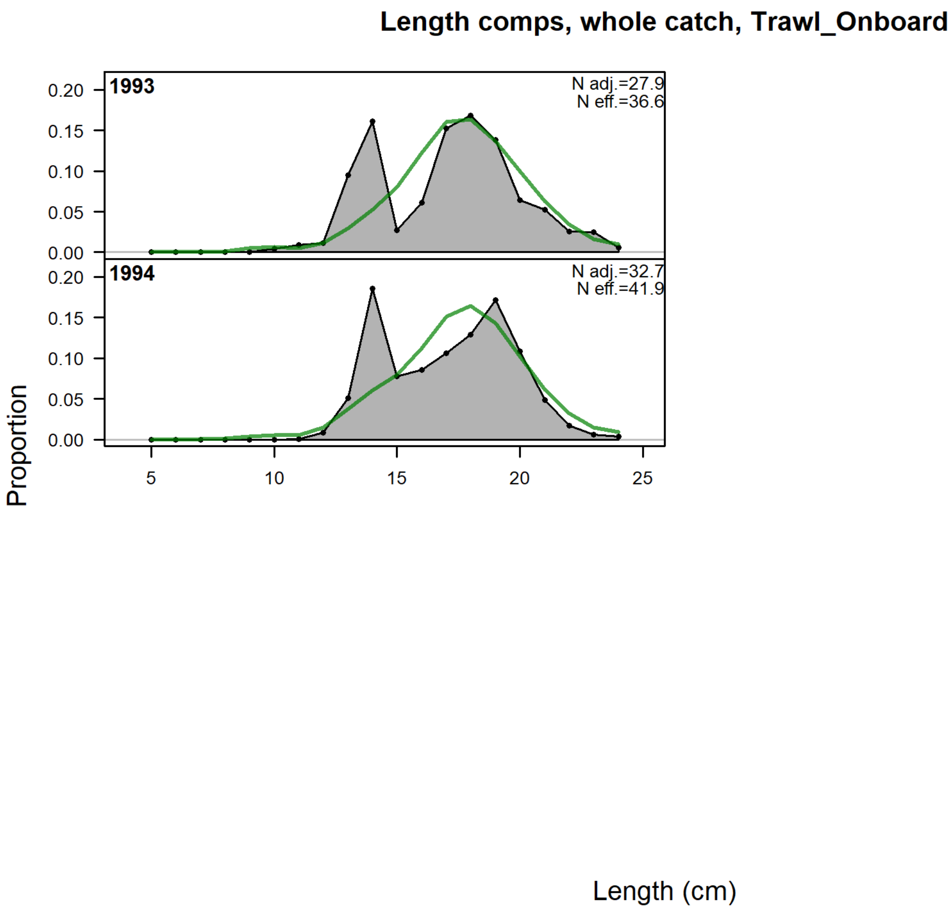
Apx Figure A.3 School Whiting length composition fits: Danish seine discarded.



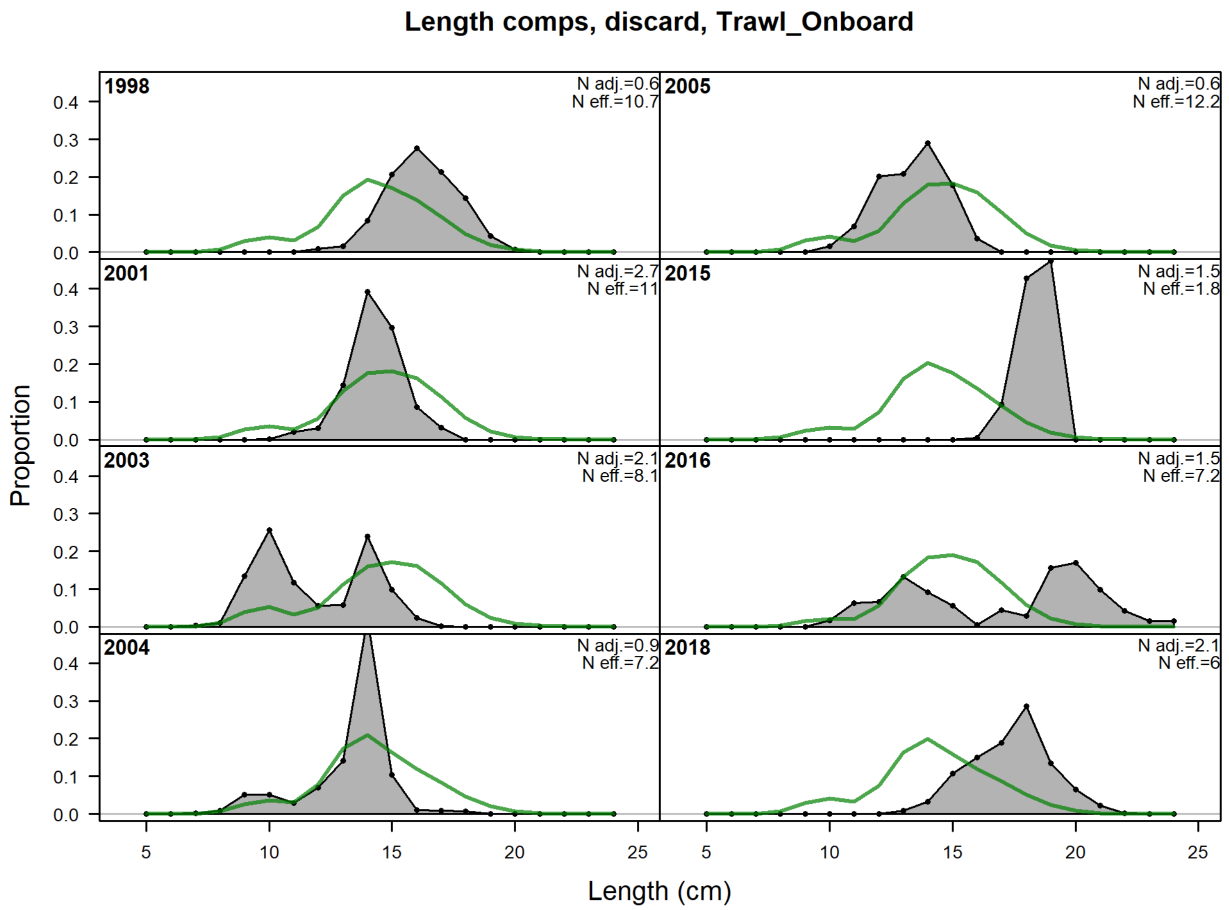
Apx Figure A.4 School Whiting length composition fits: trawl onboard retained.



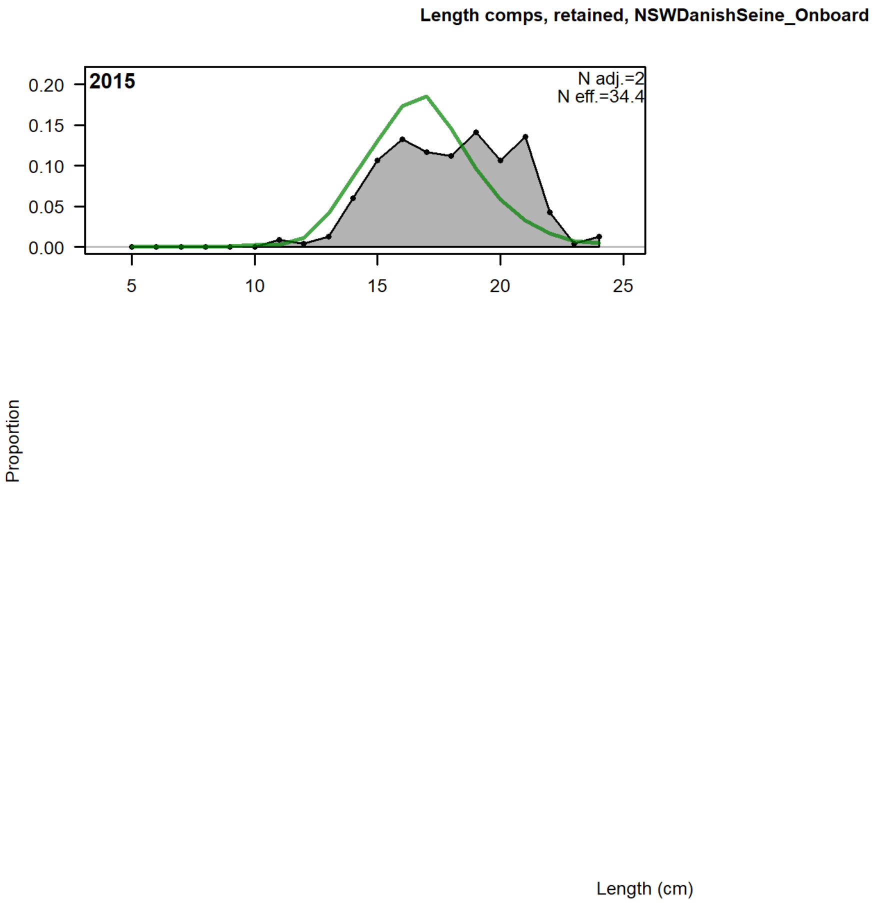
Apx Figure A.5 School Whiting length composition fits: trawl port retained.



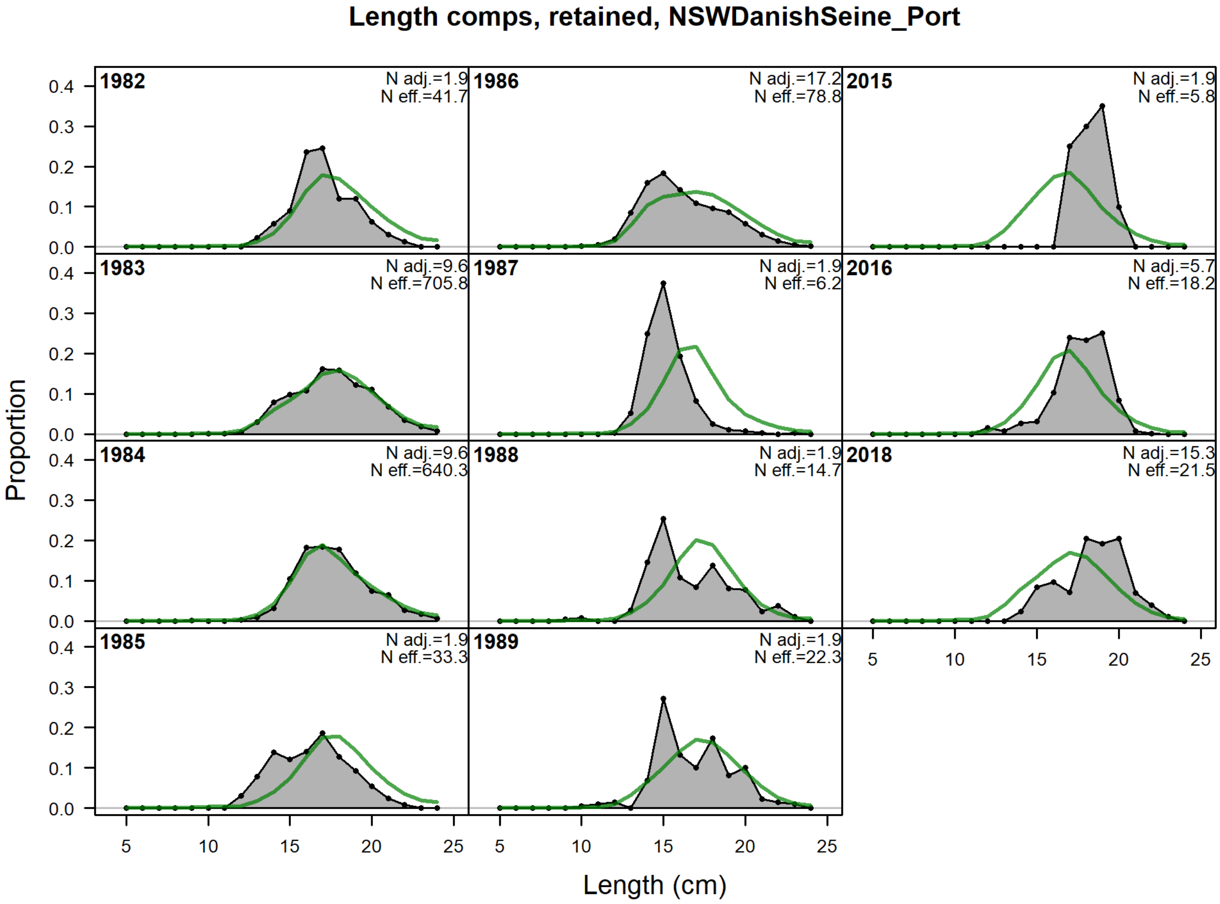
Apx Figure A.6 School Whiting length composition fits: trawl onboard whole (retained plus discarded).



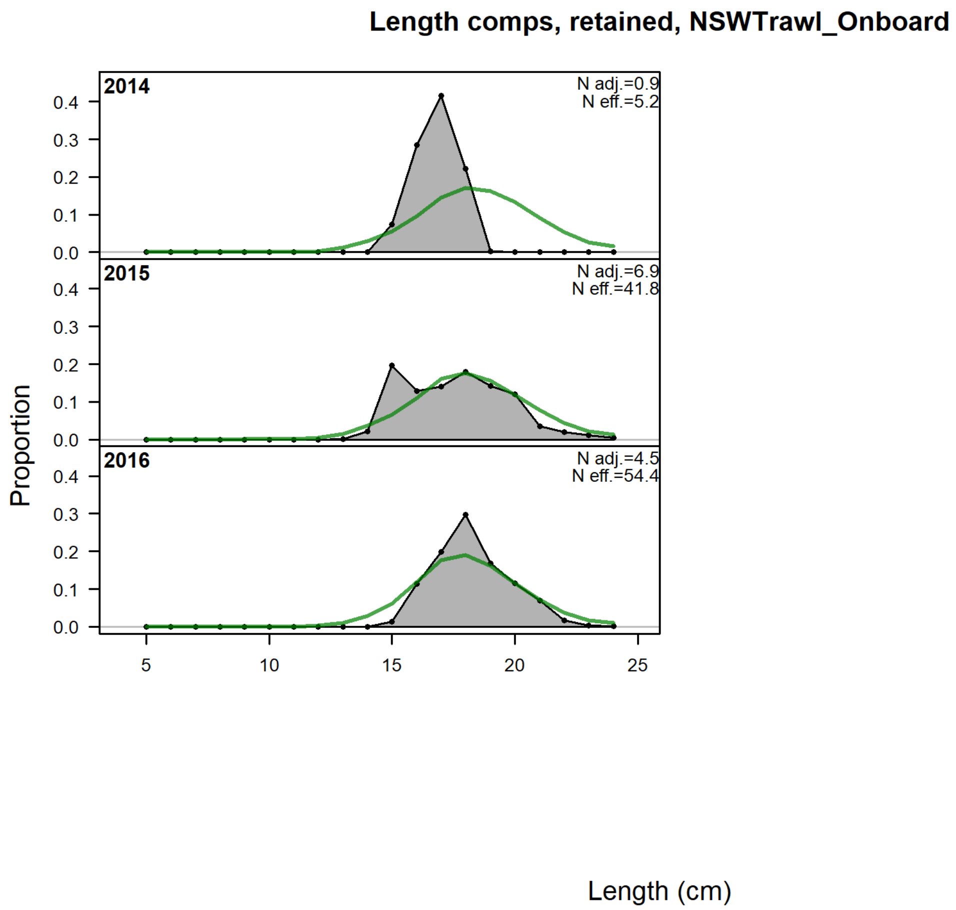
Apx Figure A.7 School Whiting length composition fits: trawl discarded.



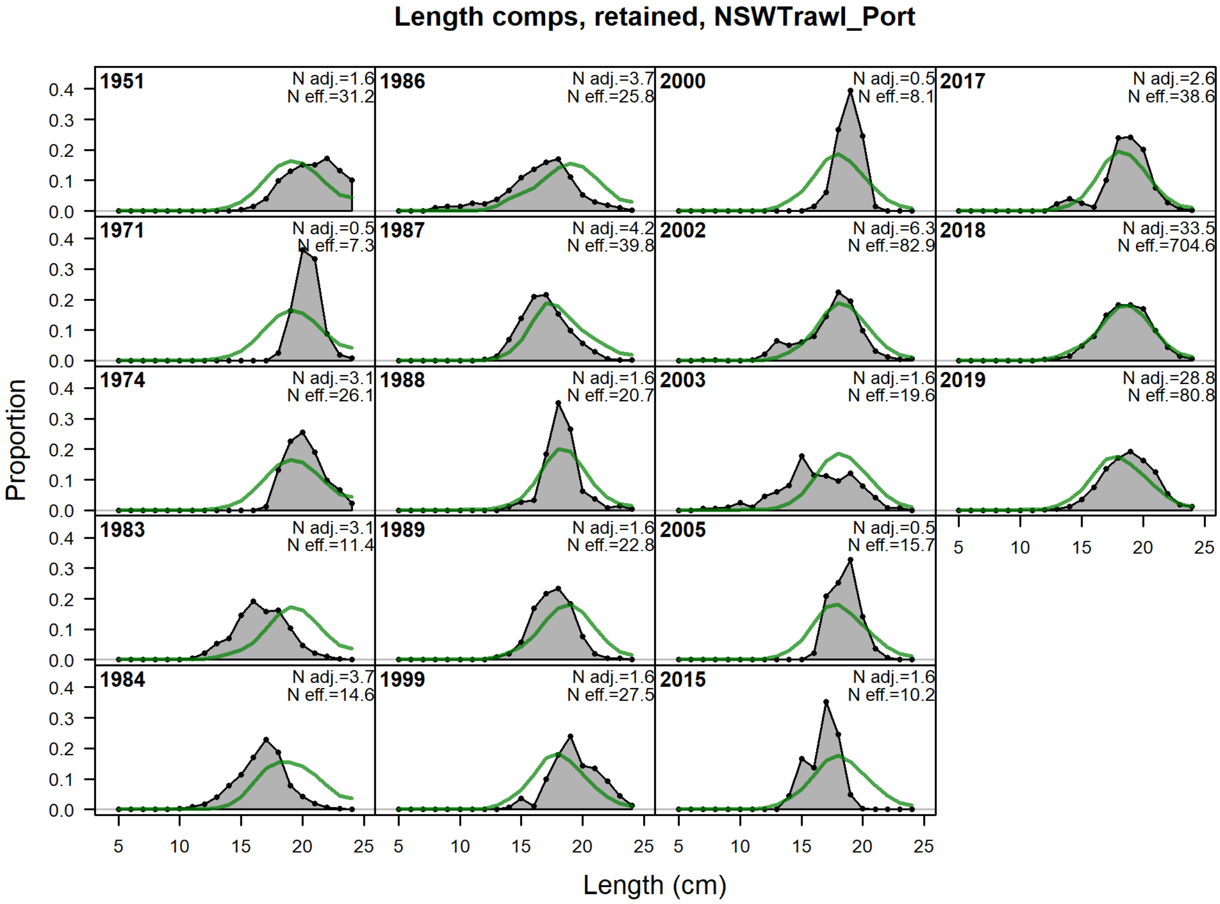
Apx Figure A.8 School Whiting length composition fits: NSW Danish seine onboard retained.



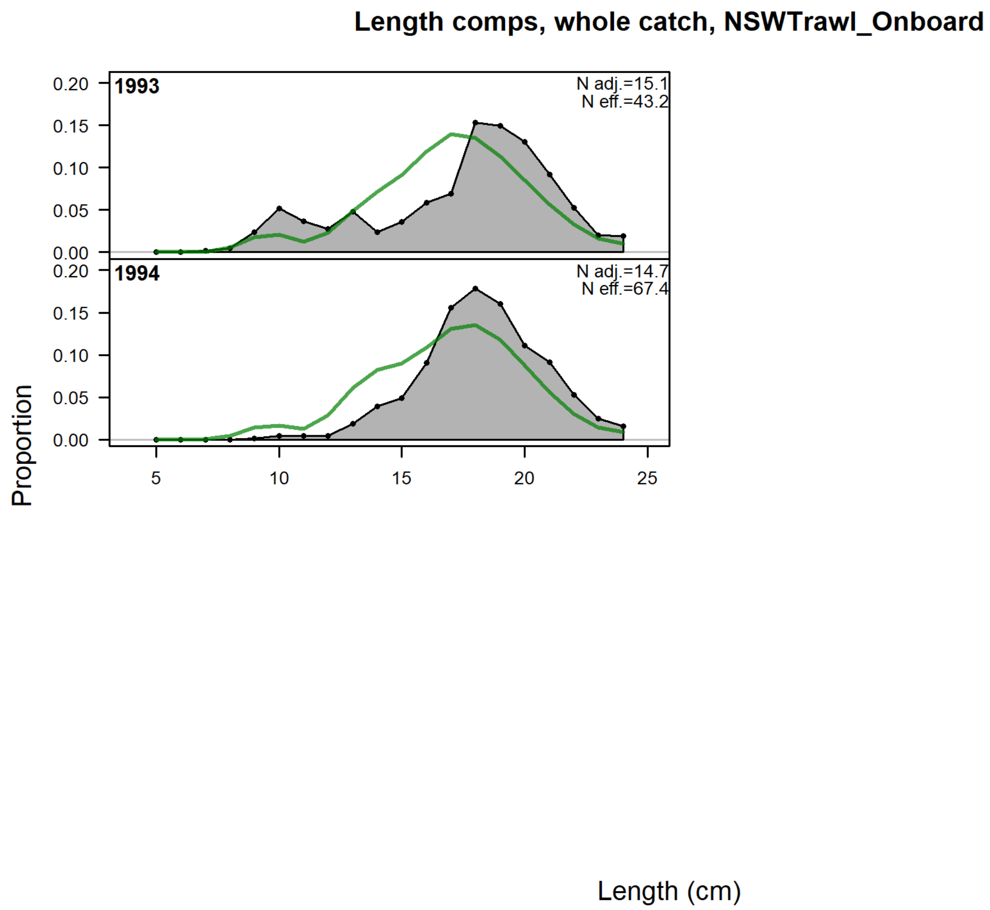
Apx Figure A.9 School Whiting length composition fits: NSW Danish seine port retained.



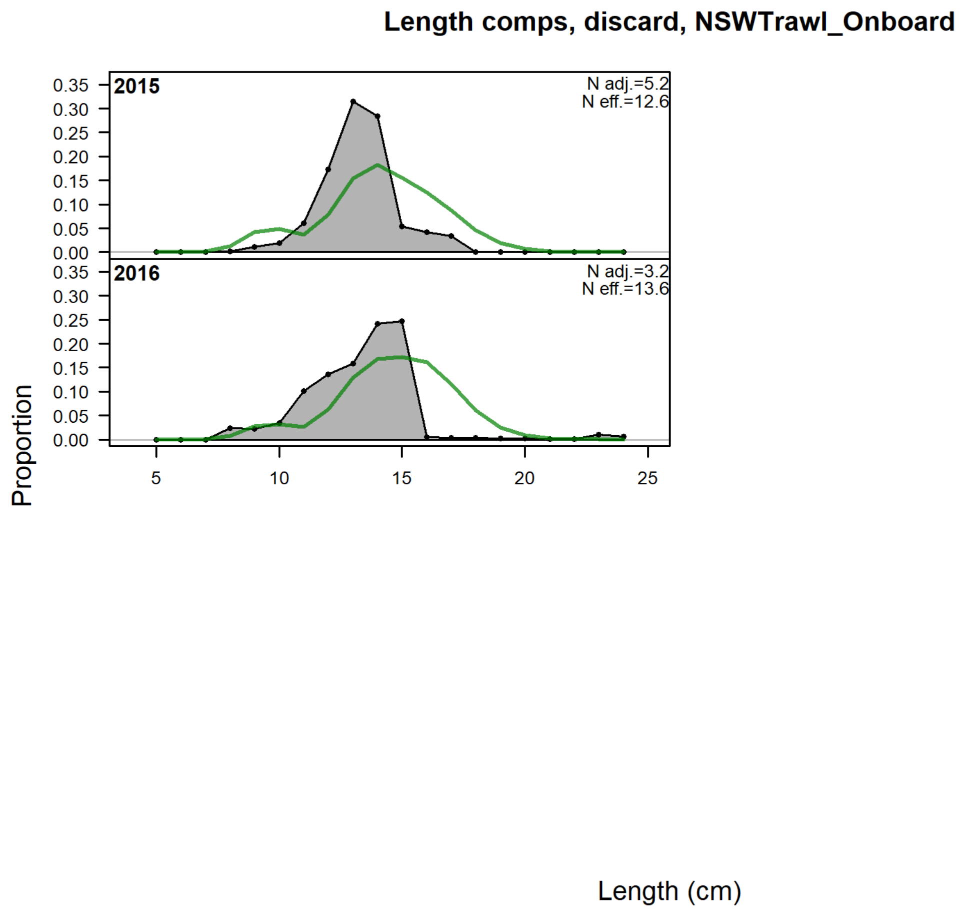
Apx Figure A.10 School Whiting length composition fits: NSW trawl onboard retained.



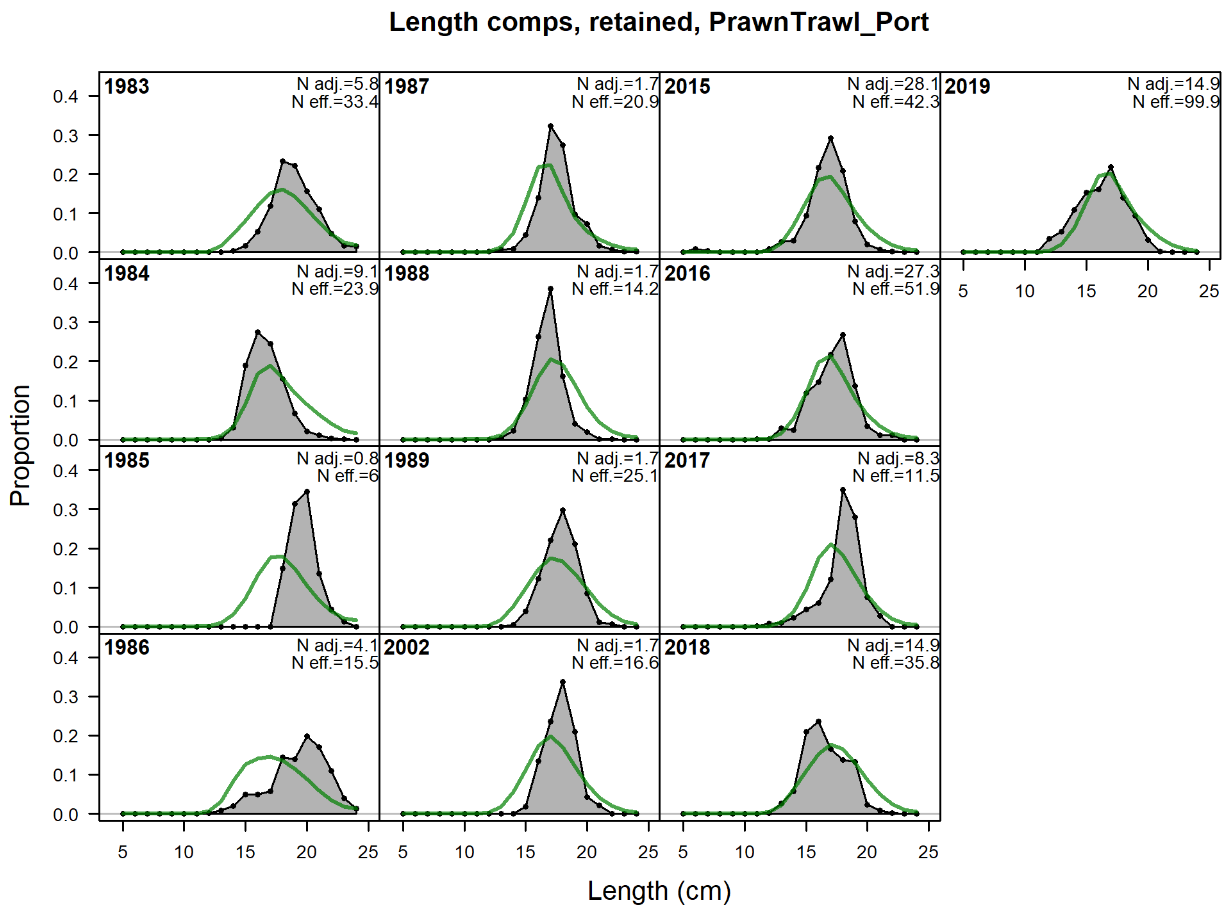
Apx Figure A.11 School Whiting length composition fits: NSW trawl port retained.



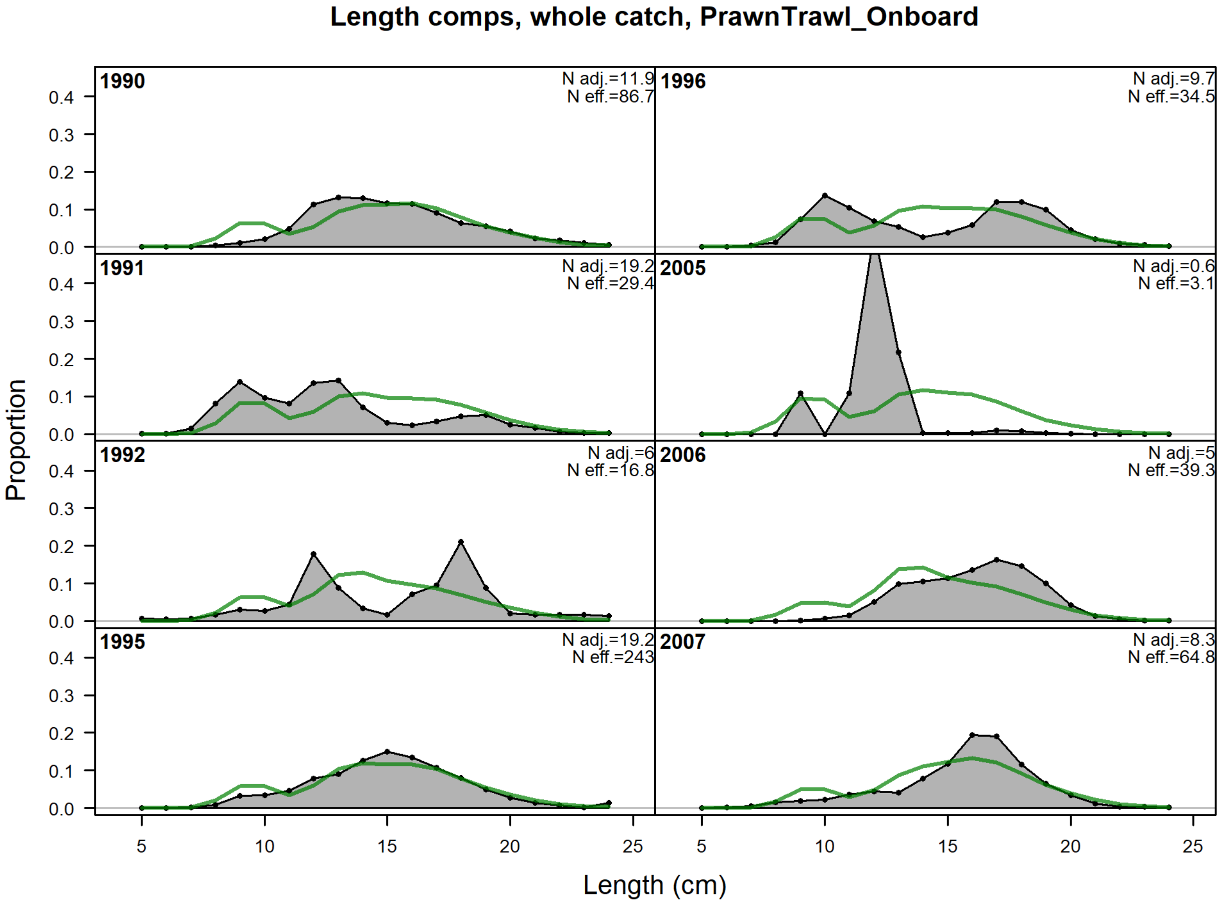
Apx Figure A.12 School Whiting length composition fits: NSW trawl onboard whole (retained plus discarded).



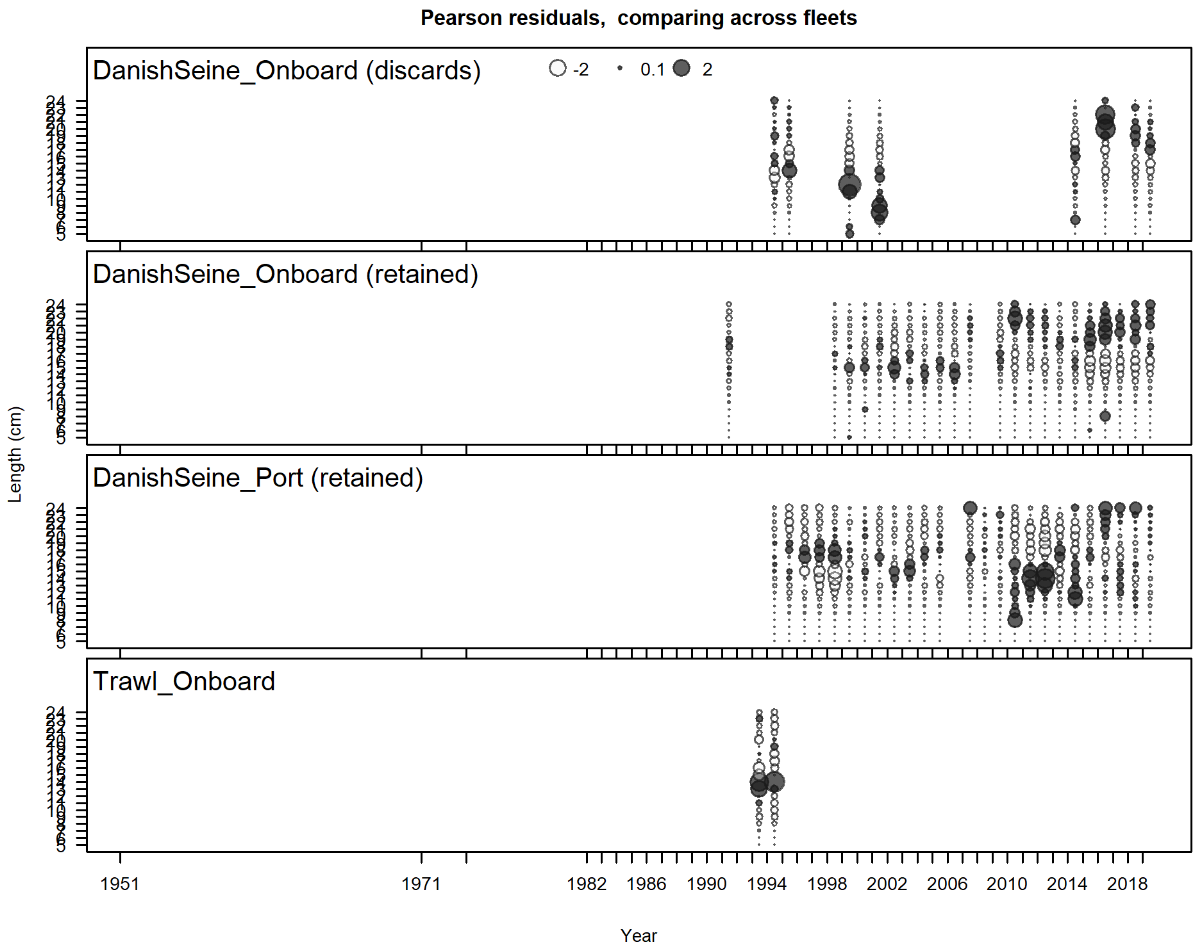
Apx Figure A.13 School Whiting length composition fits: NSW trawl discarded.



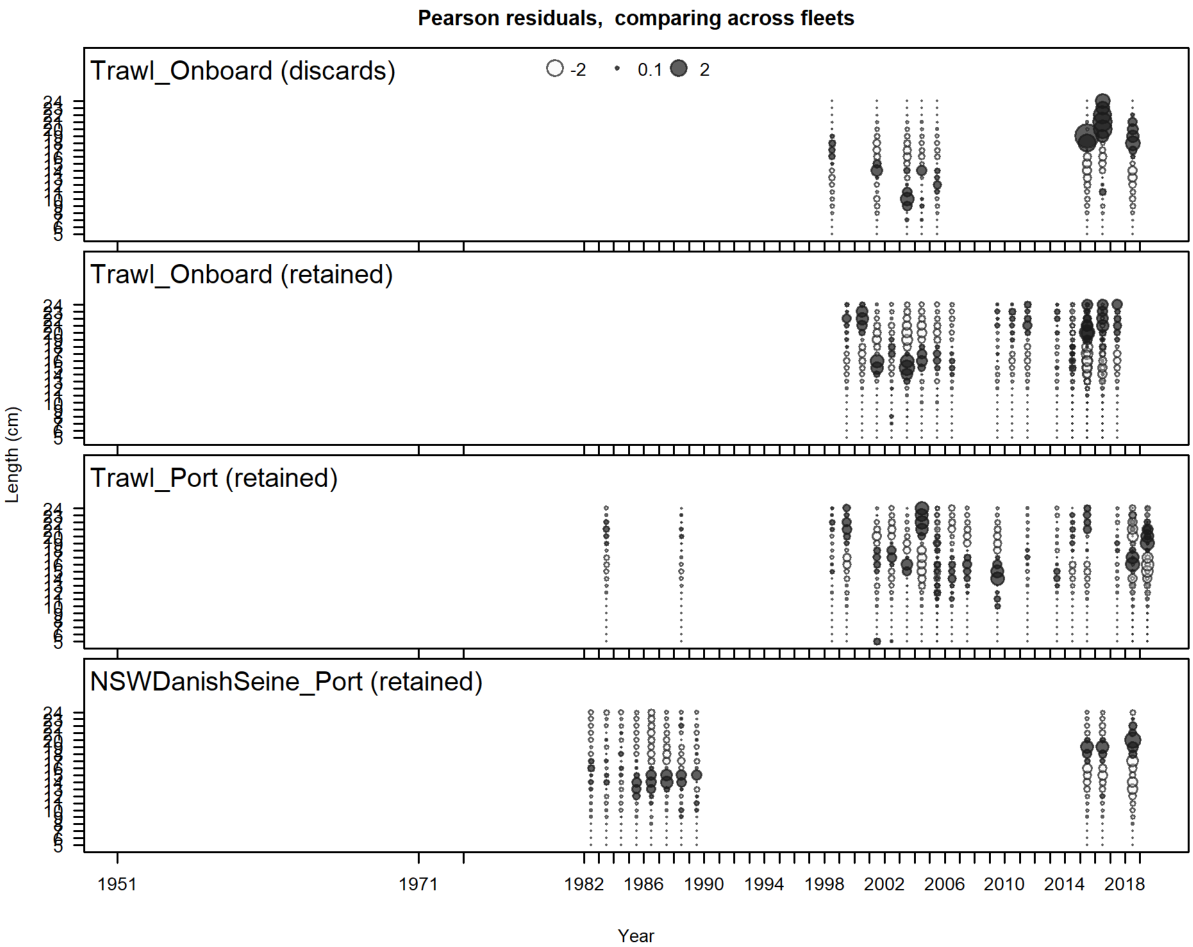
Apx Figure A.14 School Whiting length composition fits: prawn trawl onboard retained.



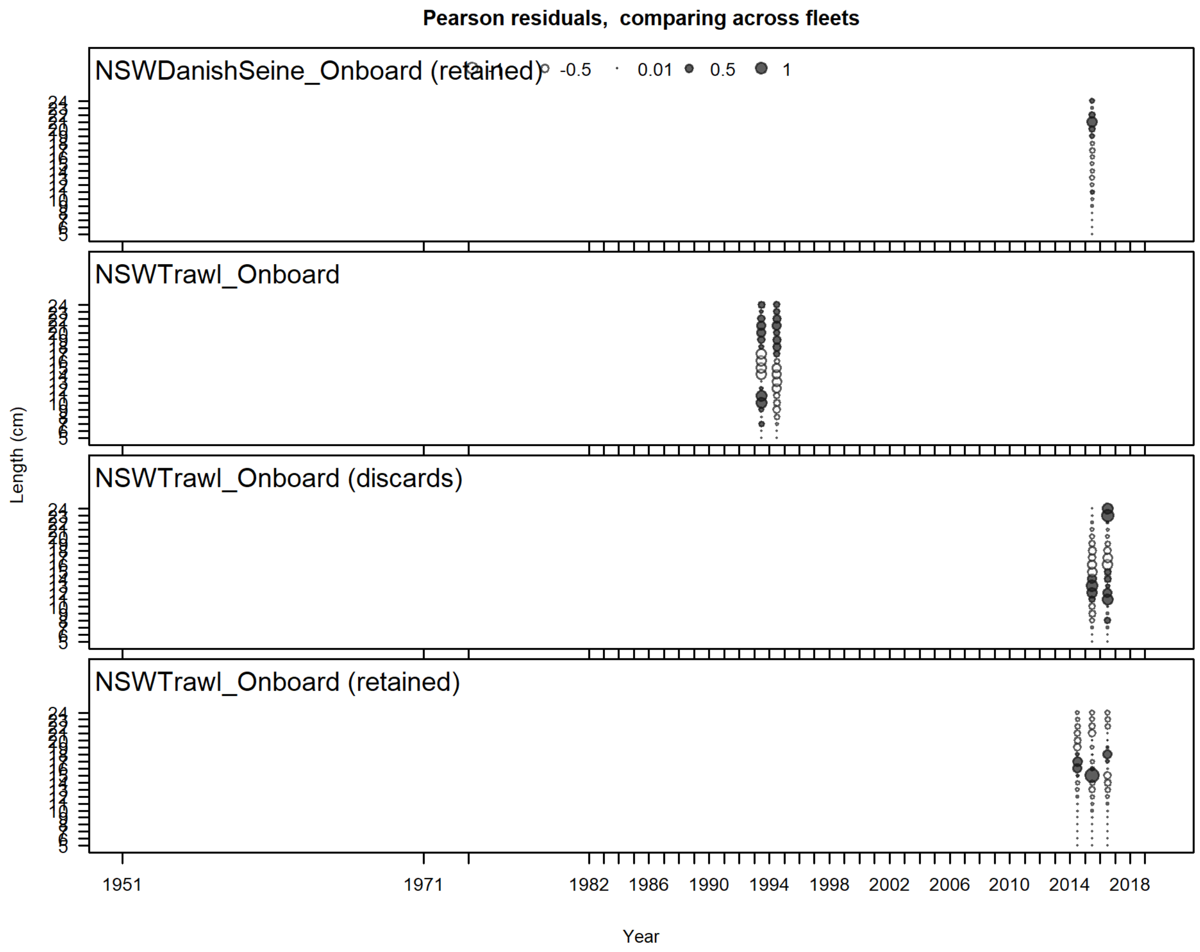
Apx Figure A.15 School Whiting length composition fits: prawn trawl onboard whole (retained plus discarded).



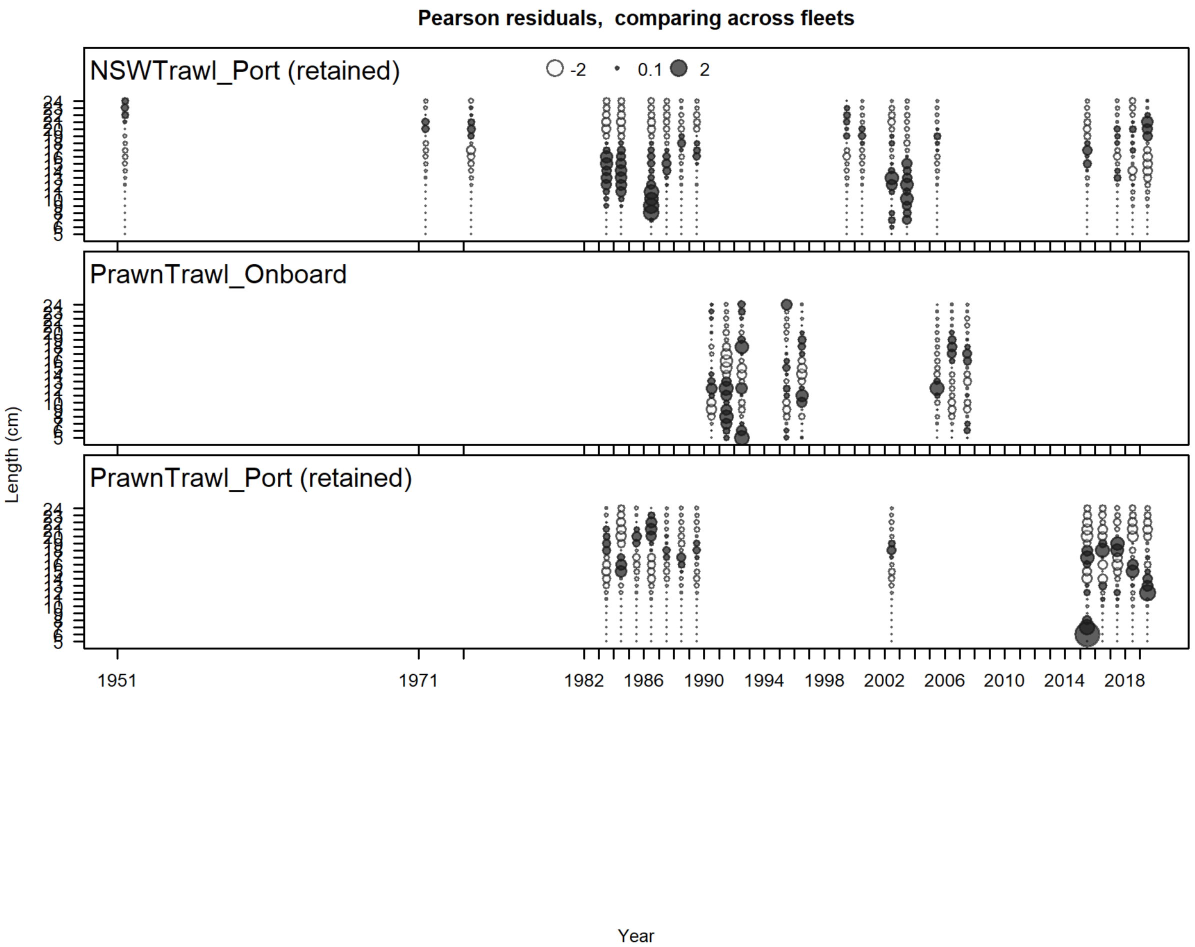
Apx Figure A.16 Residuals from the annual length composition data for School Whiting displayed by year and fleet for Danish seine (retained and discarded) and trawl onboard (whole).



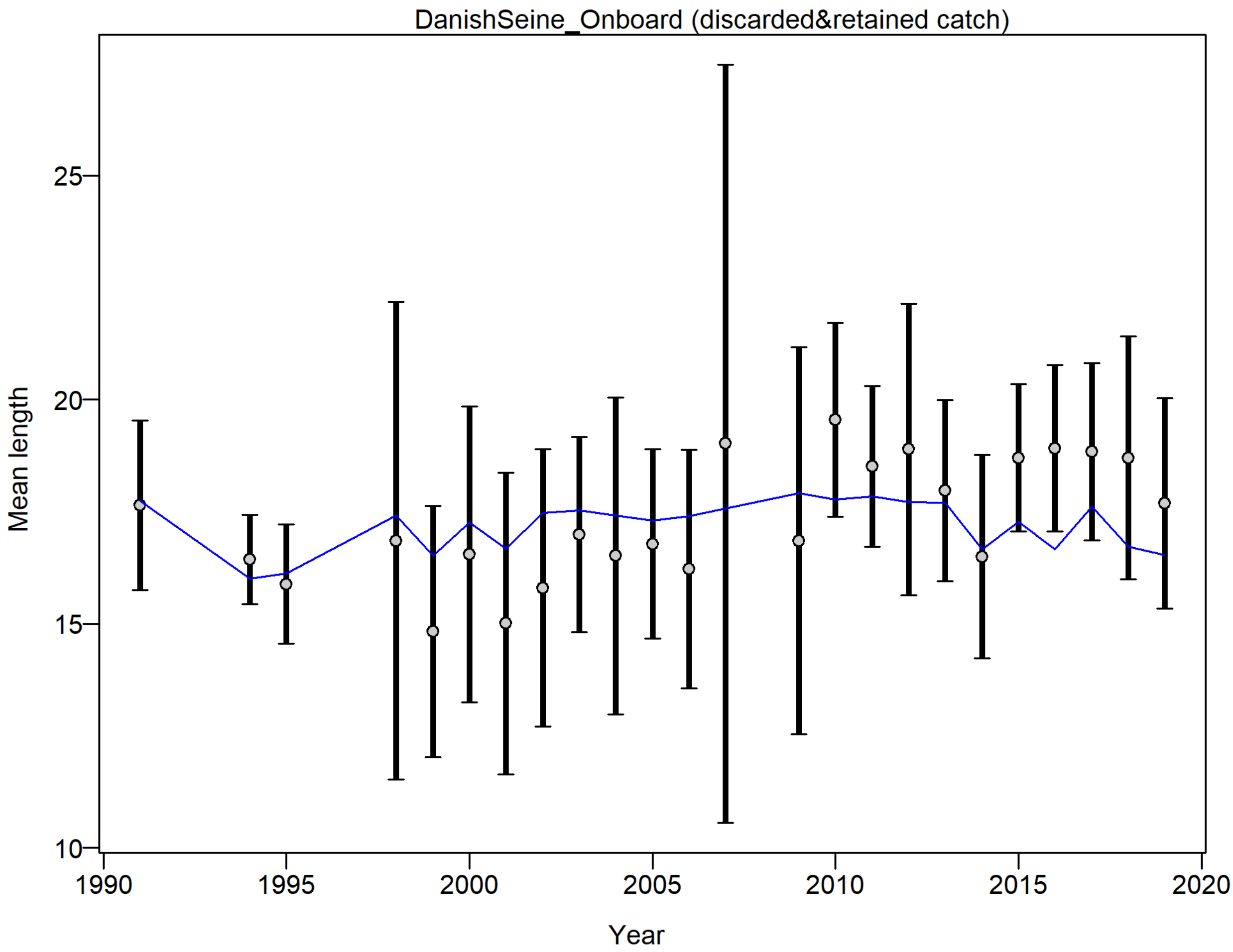
Apx Figure A.17 Residuals from the annual length composition data for School Whiting displayed by year and fleet for trawl (retained) and NSW Danish seine port (retained).



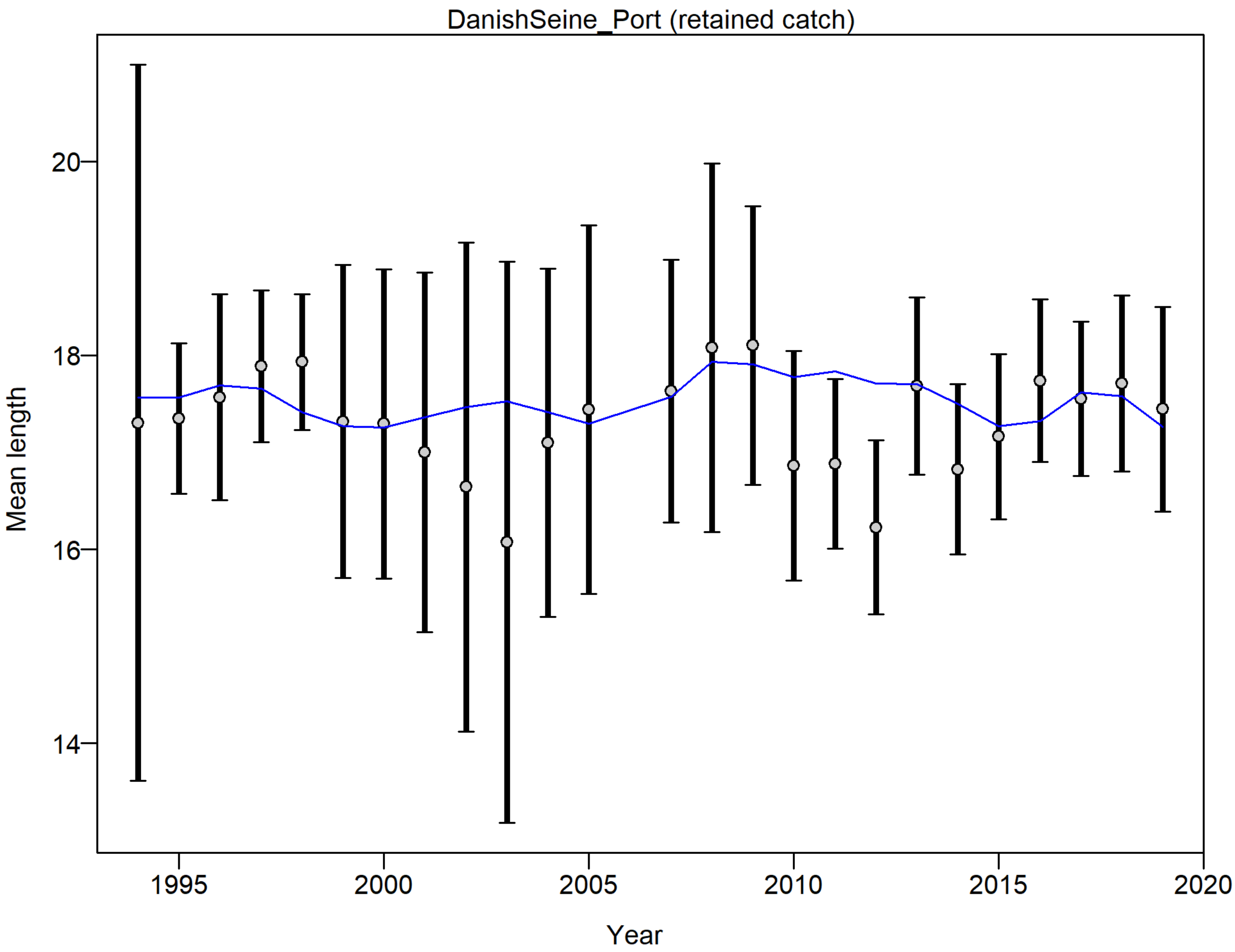
Apx Figure A.18 Residuals from the annual length composition data for School Whiting displayed by year and fleet for NSW Danish seine onboard (retained) and NSW trawl (onboard).



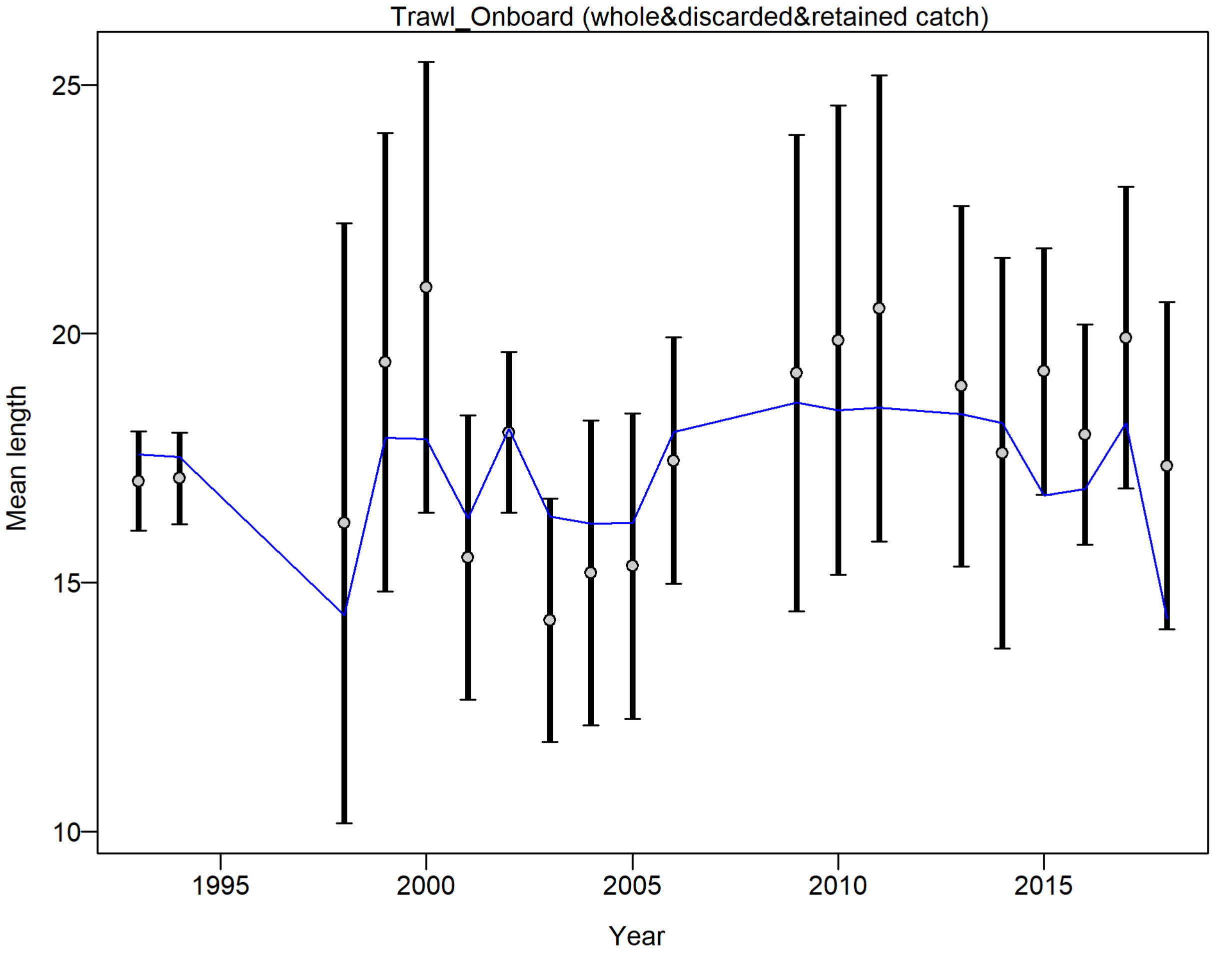
Apx Figure A.19 Residuals from the annual length composition data for School Whiting displayed by year and fleet for NSW trawl (port) and prawn trawl.



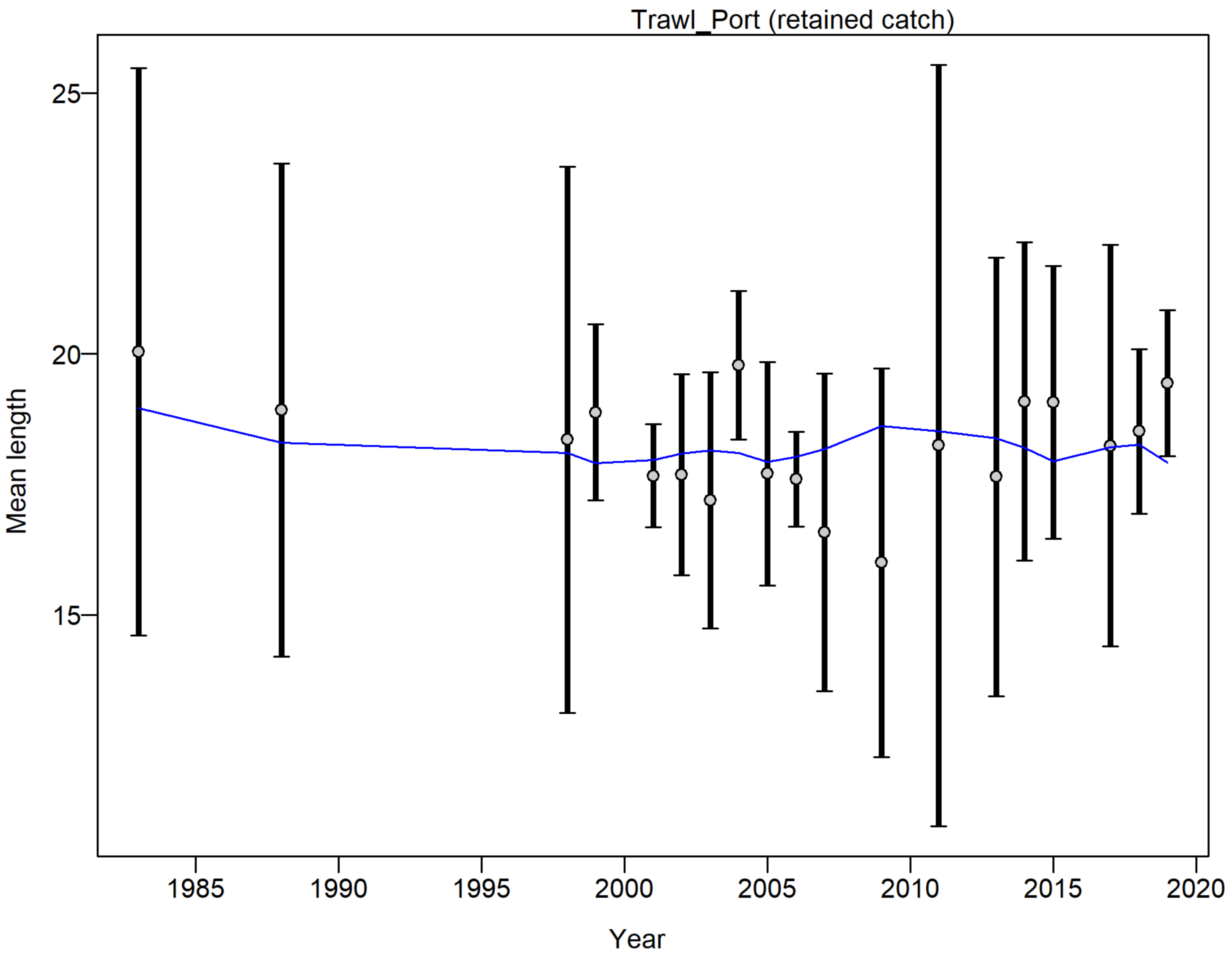
Apx Figure A.20 Mean length for School Whiting from Danish seine onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



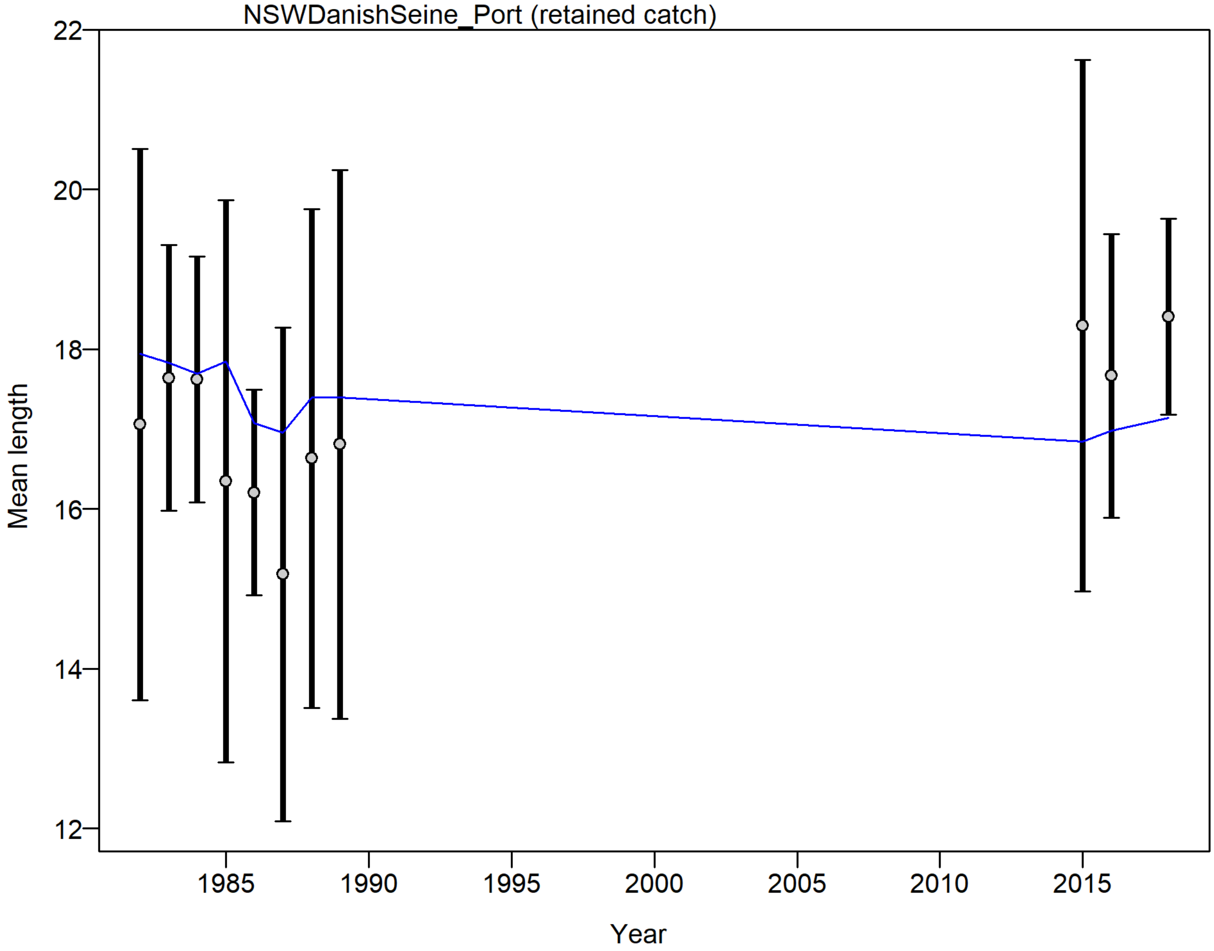
Apx Figure A.21 Mean length for School Whiting from Danish seine port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



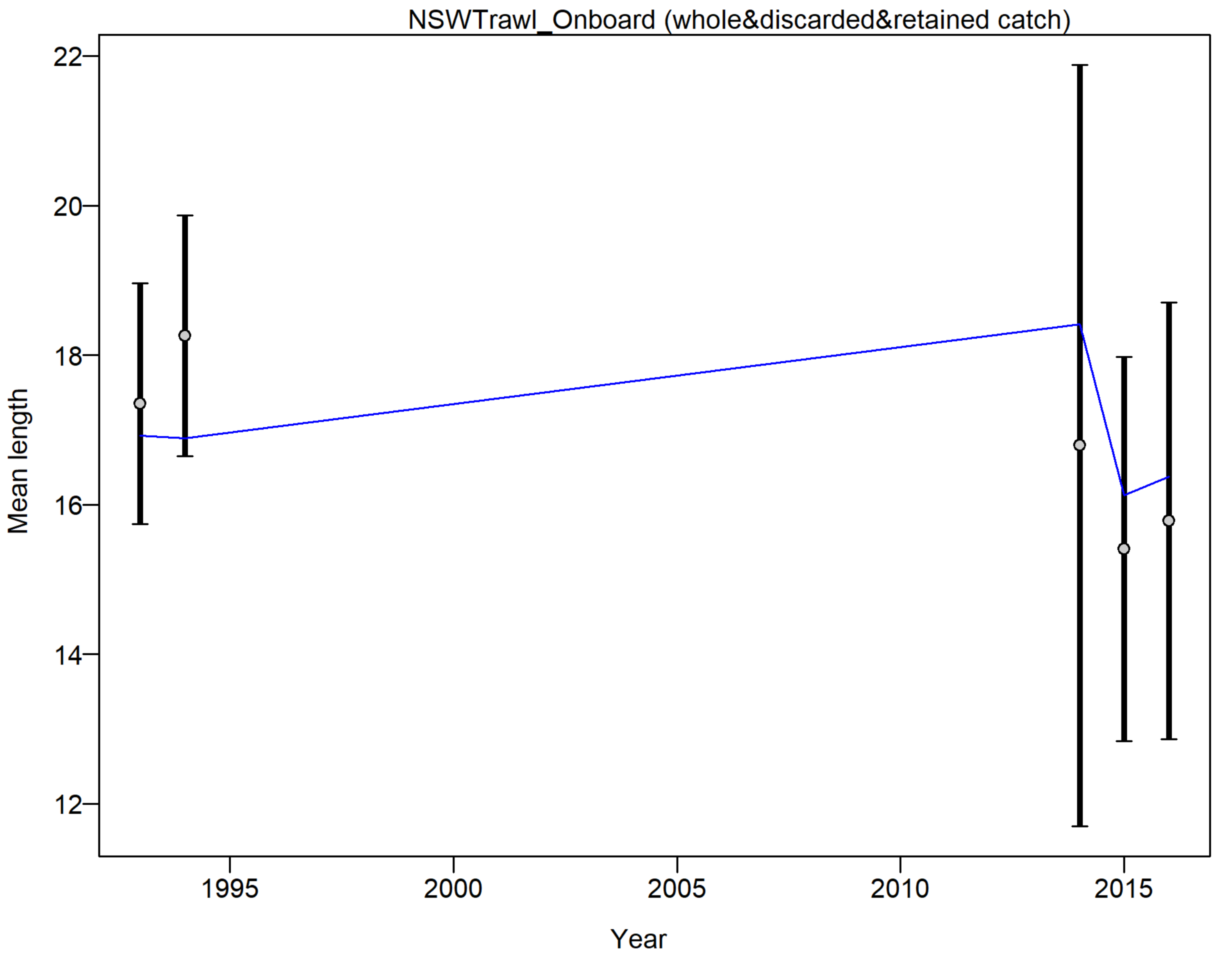
Apx Figure A.22 Mean length for School Whiting from trawl onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



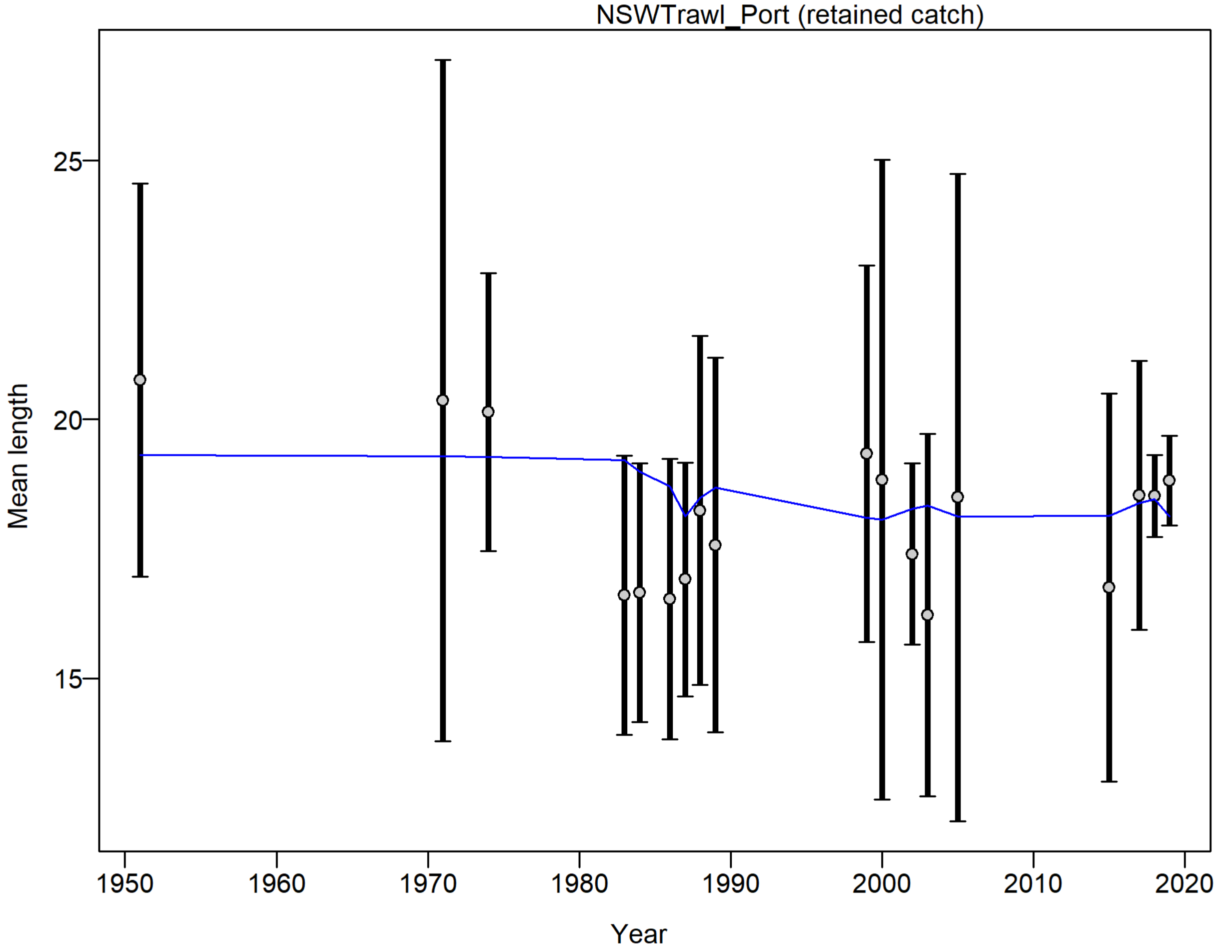
Apx Figure A.23 Mean length for School Whiting from trawl port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



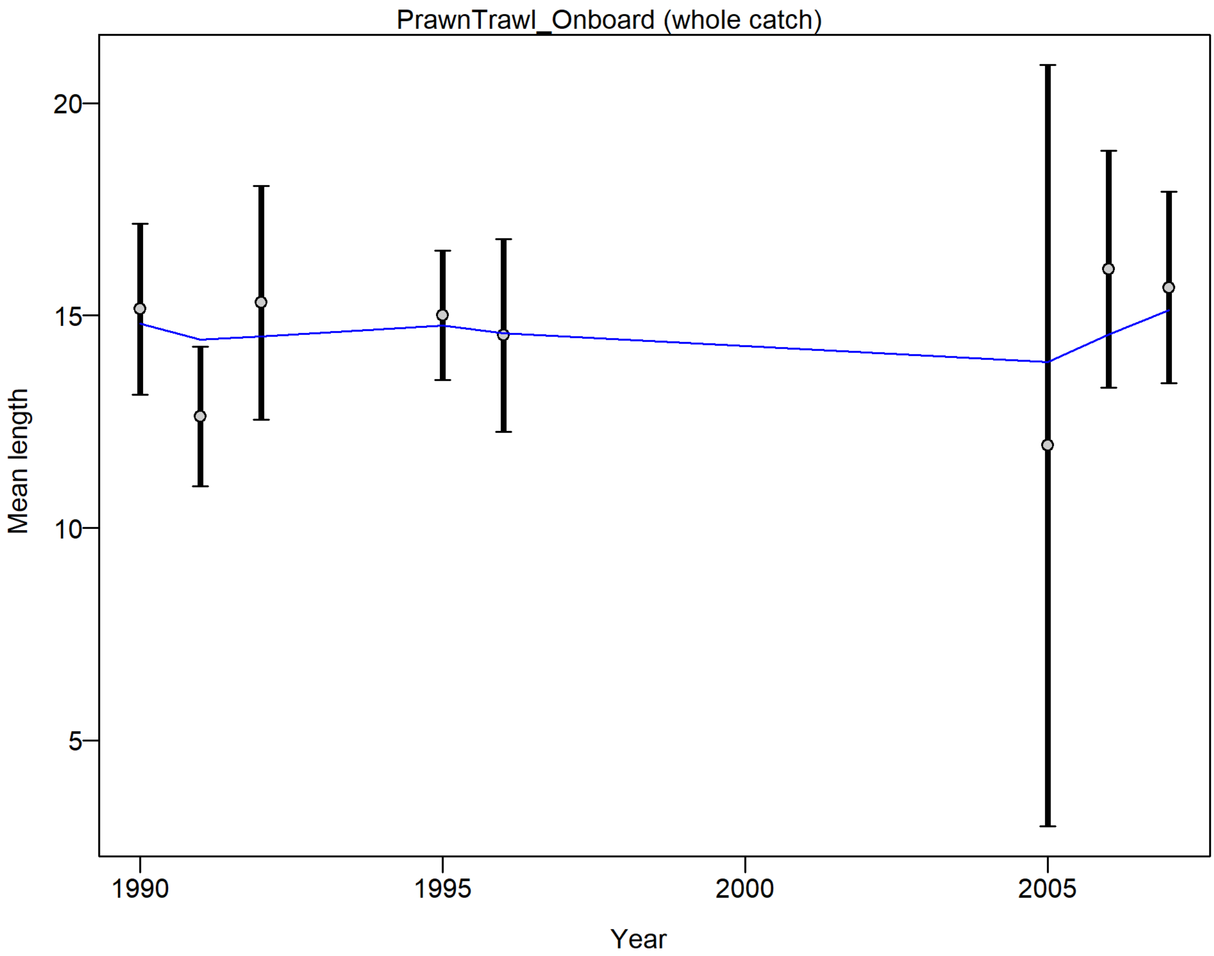
Apx Figure A.24 Mean length for School Whiting from NSW Danish seine port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



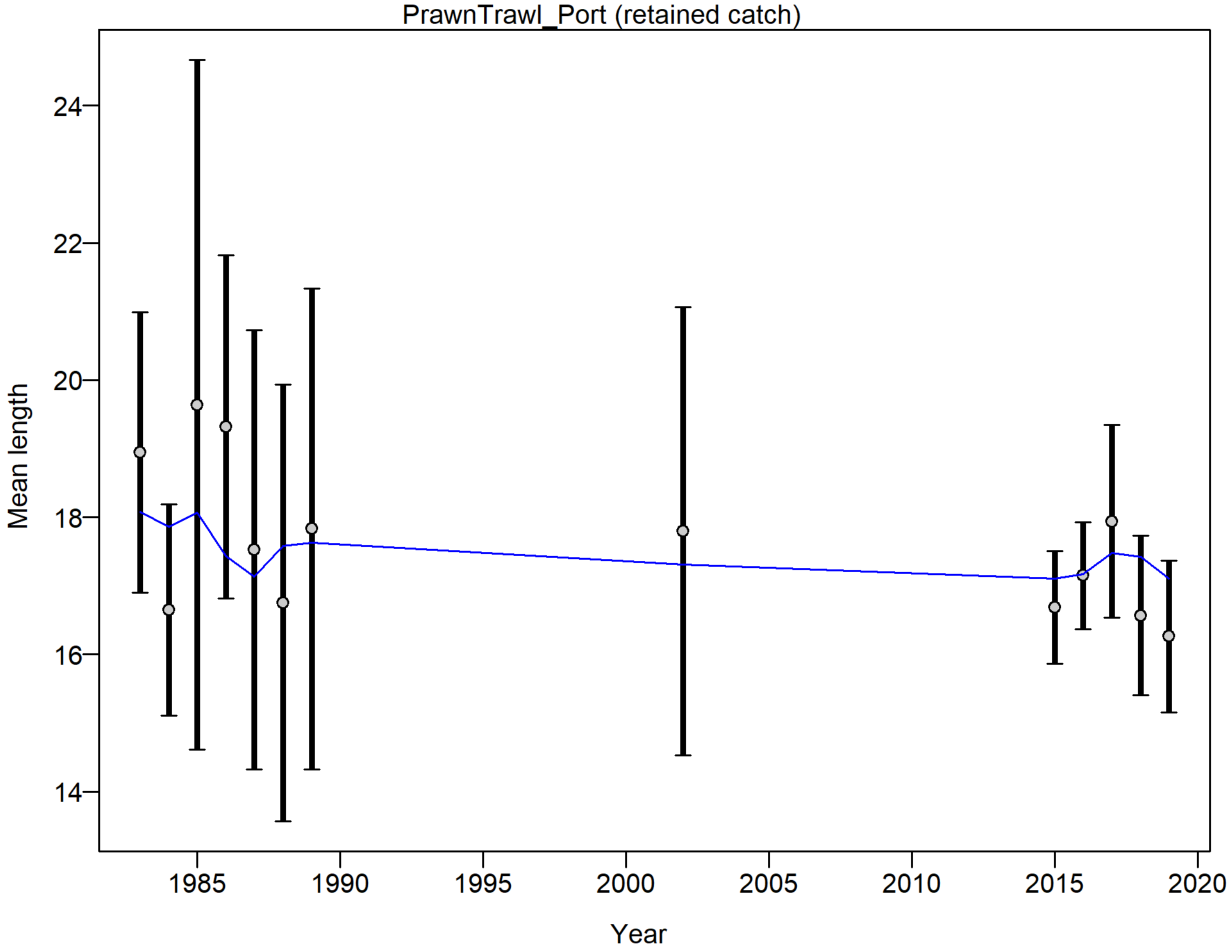
Apx Figure A.25 Mean length for School Whiting from NSW trawl onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



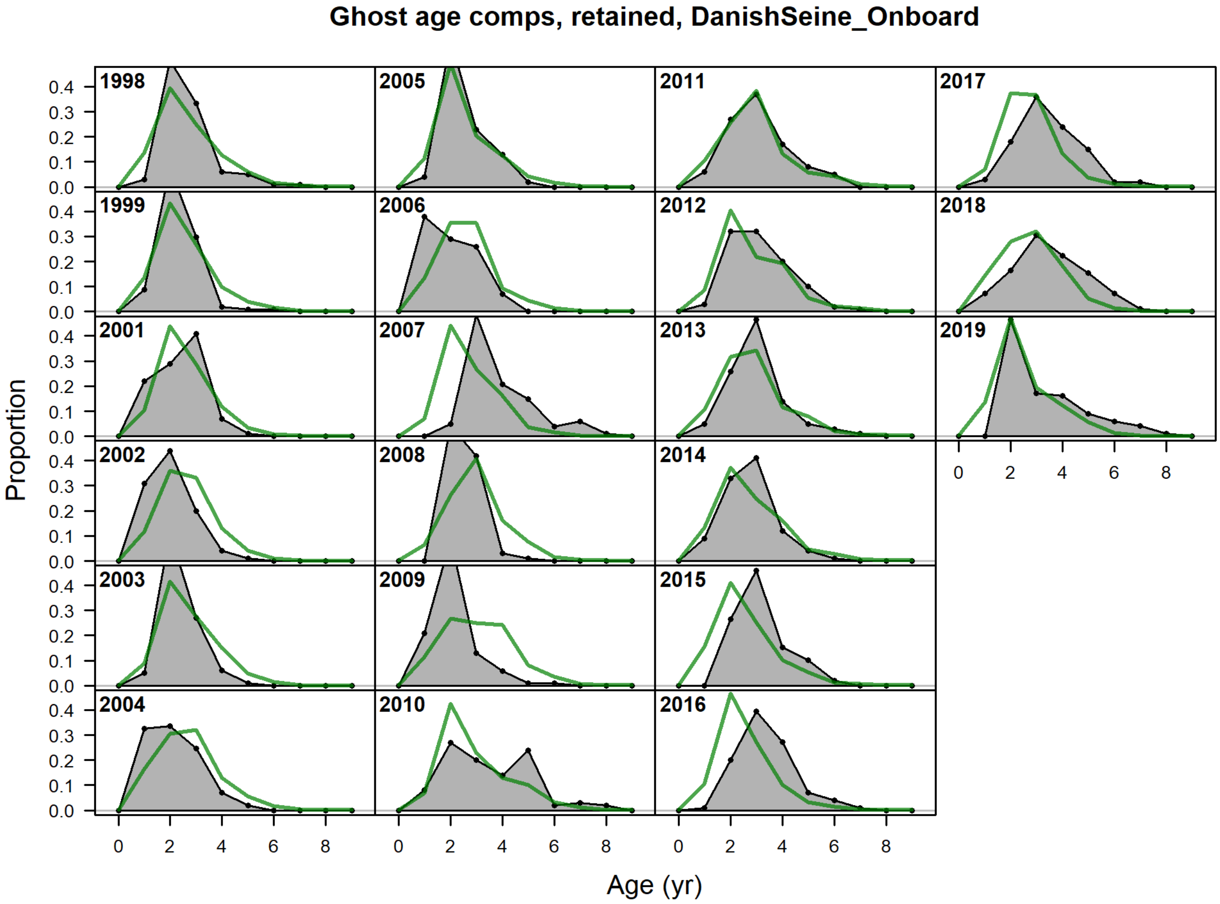
Apx Figure A.26 Mean length for School Whiting from NSW trawl port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



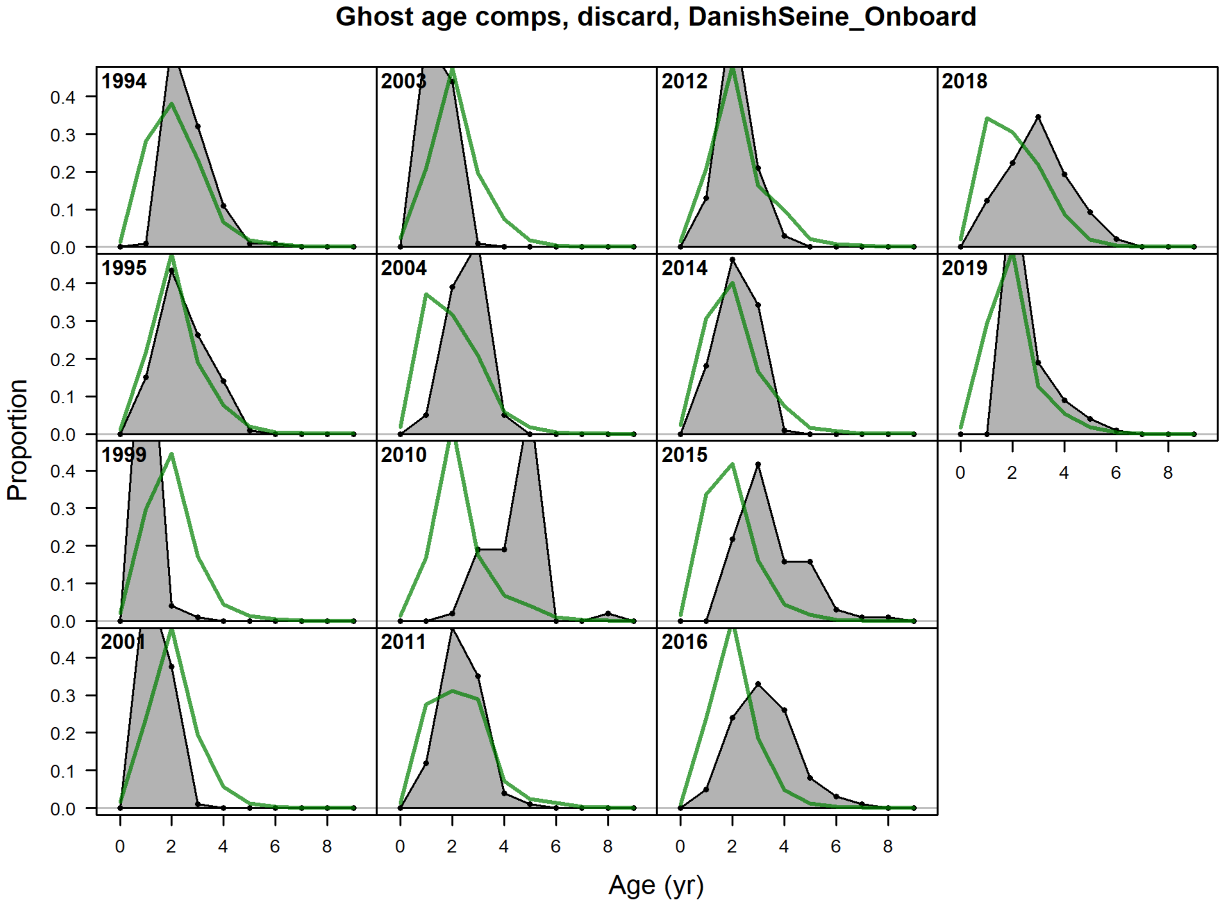
Apx Figure A.27 Mean length for School Whiting from prawn trawl onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



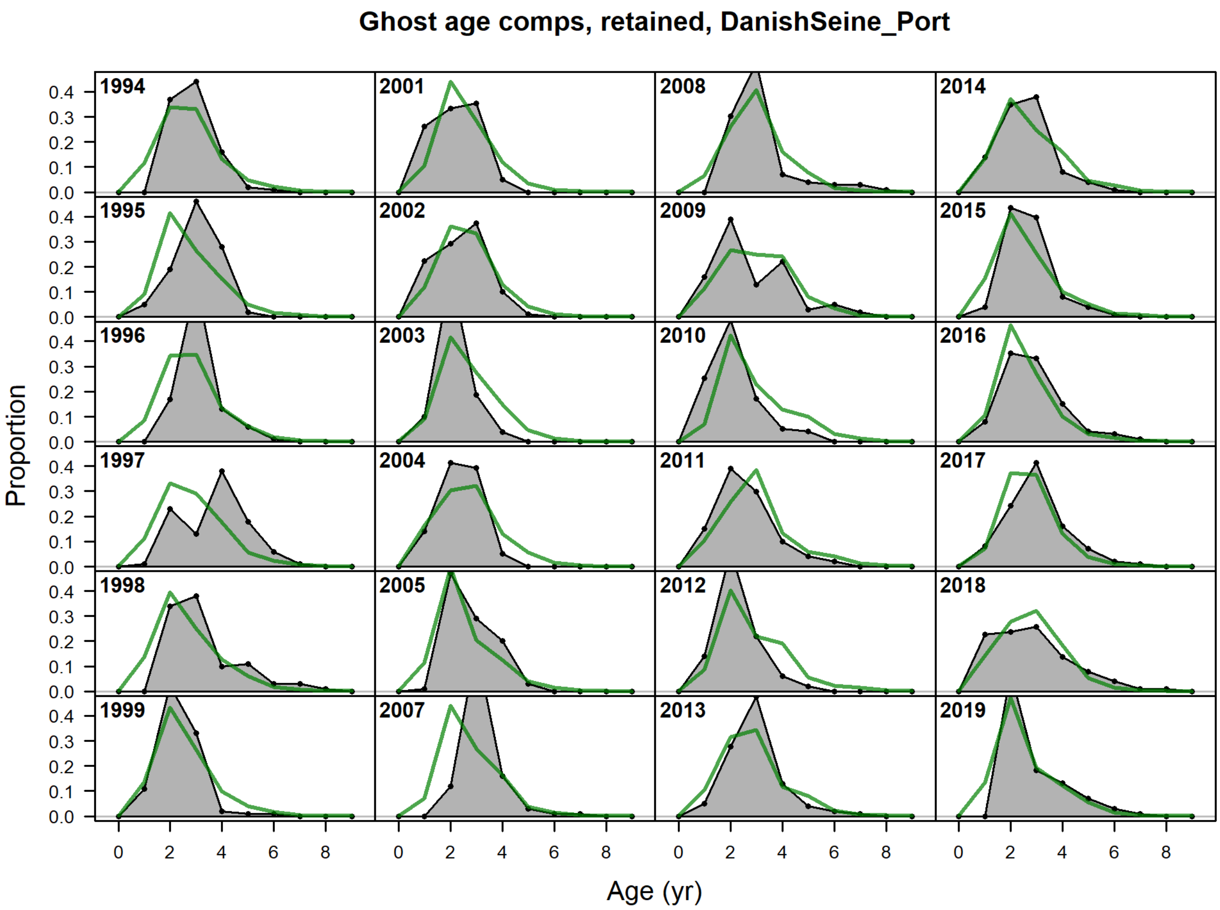
Apx Figure A.28 Mean length for School Whiting from prawn trawl port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



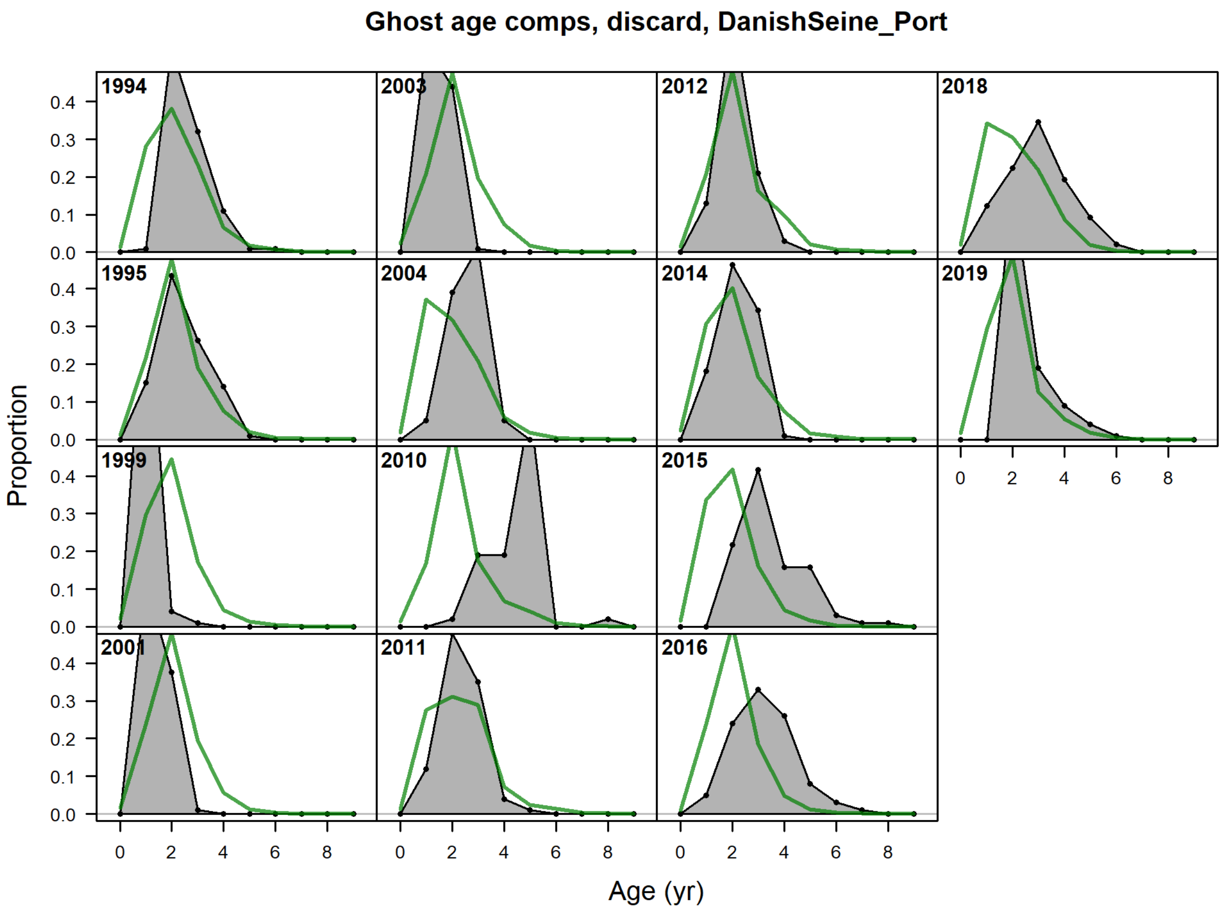
Apx Figure A.29 Implied fits to age compositions for School Whiting Danish seine onboard (retained).



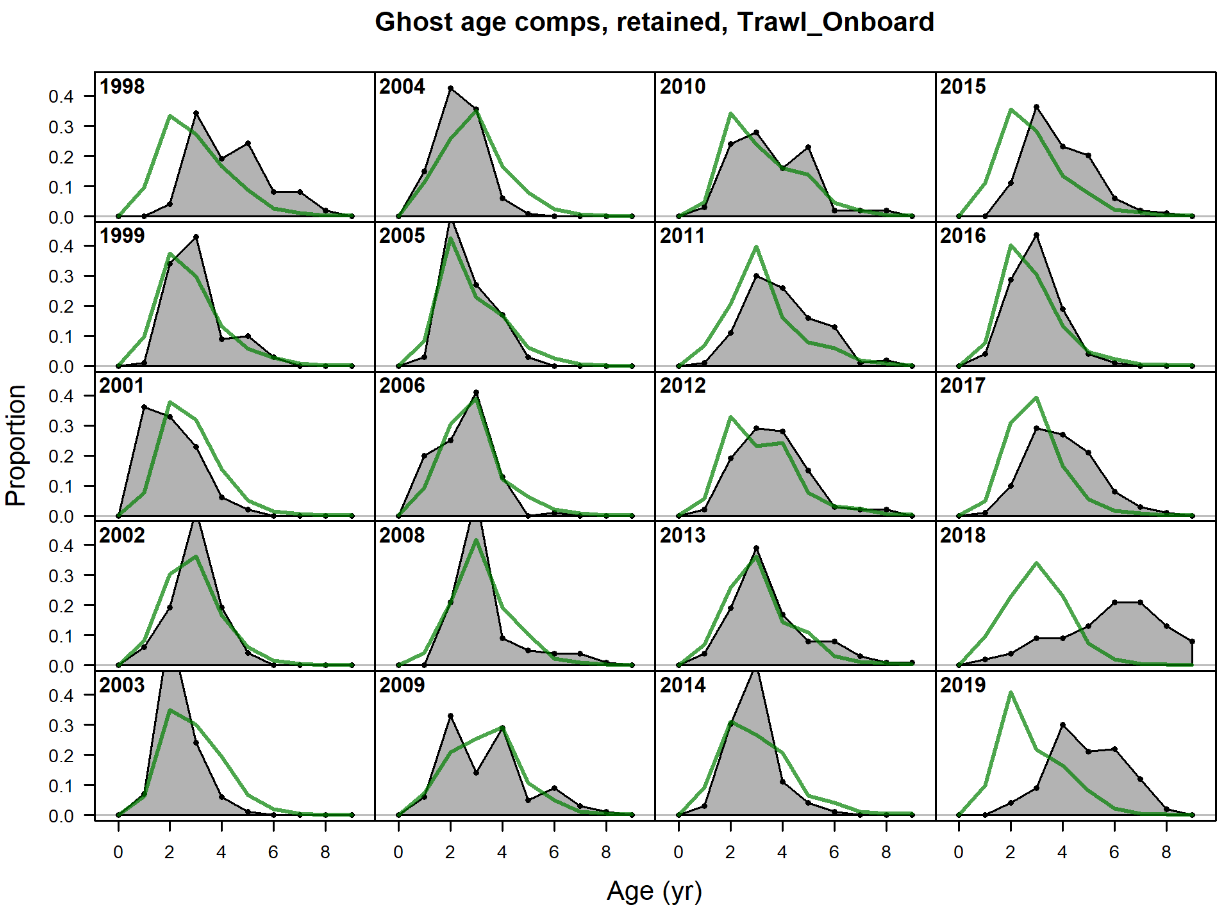
Apx Figure A.30 Implied fits to age compositions for School Whiting Danish seine onboard (discarded).



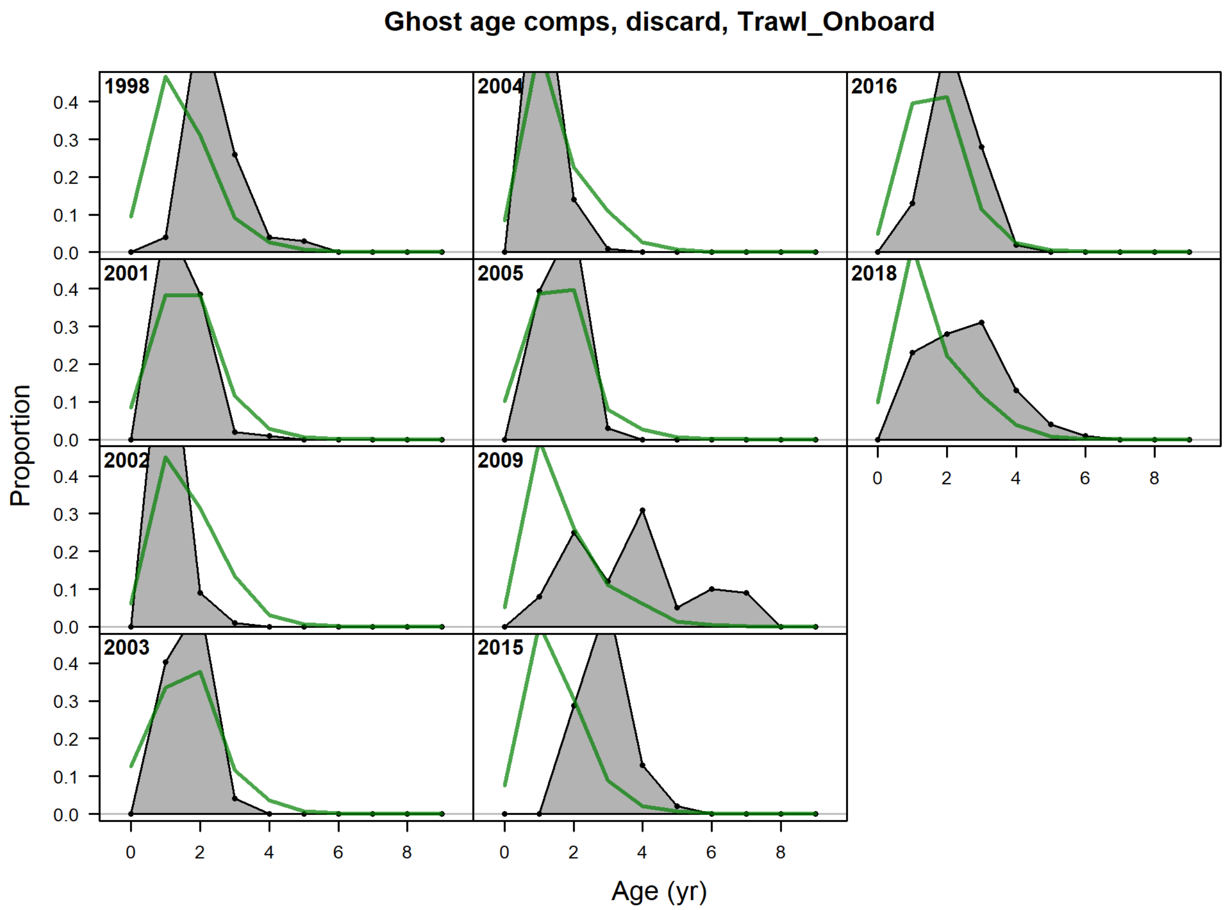
Apx Figure A.31 Implied fits to age compositions for School Whiting Danish seine port (retained).



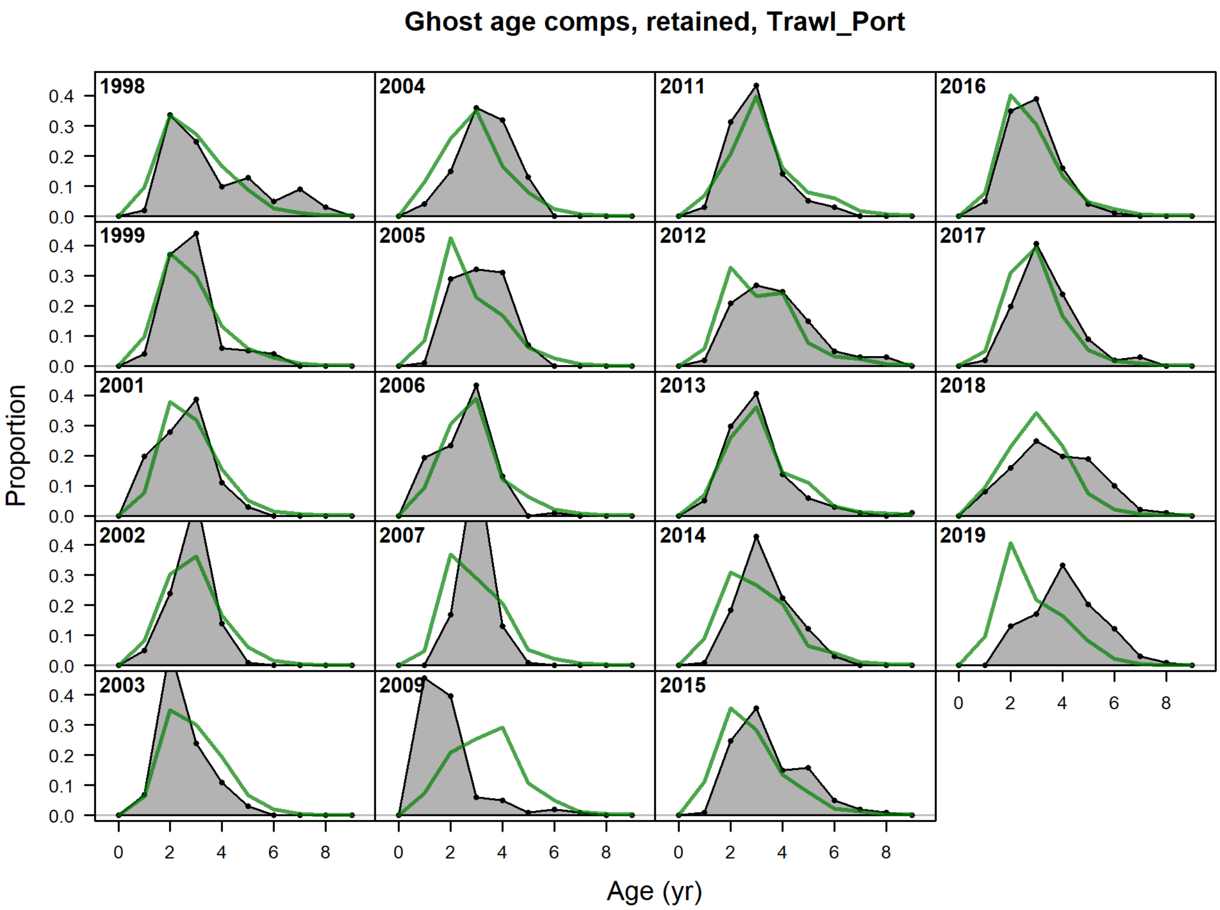
Apx Figure A.32 Implied fits to age compositions for School Whiting Danish seine port (discarded).



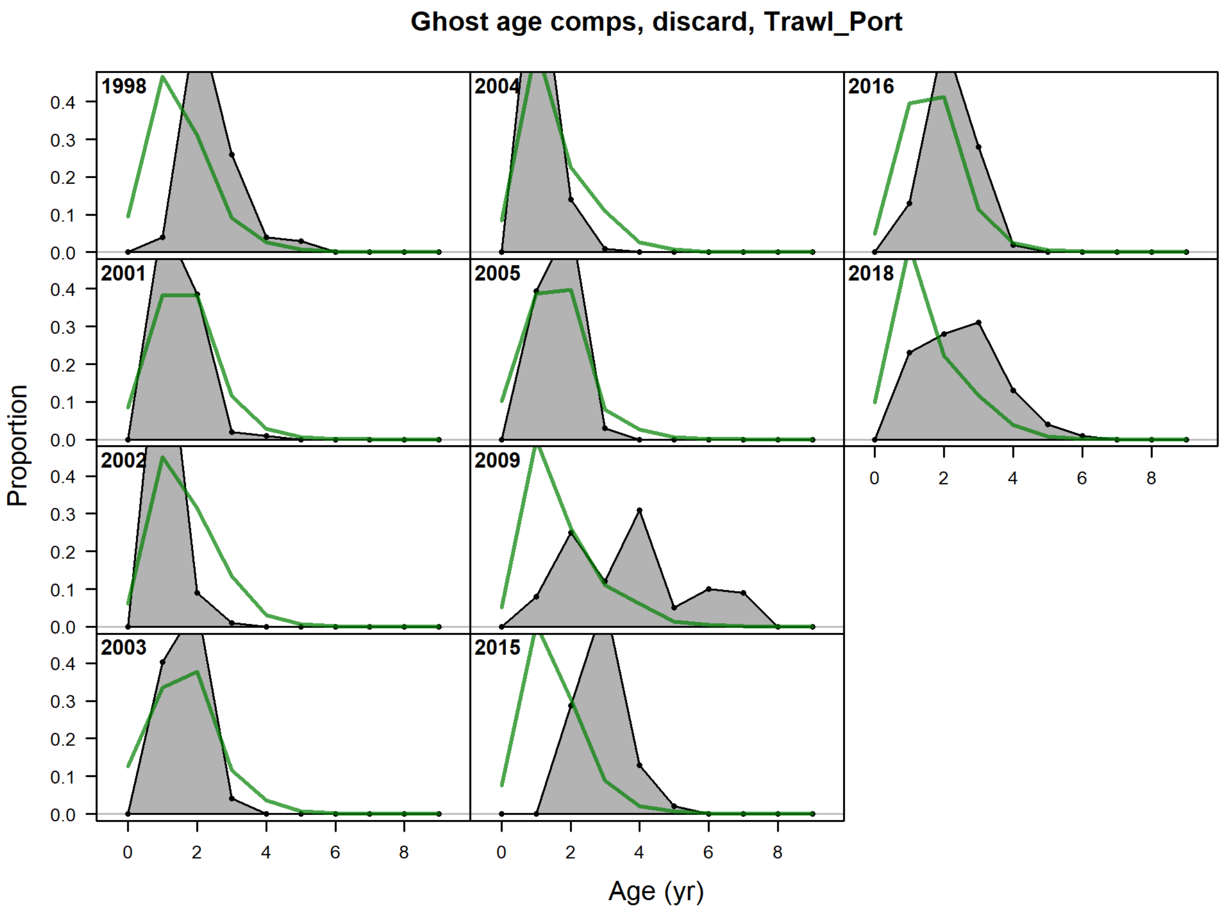
Apx Figure A.33 Implied fits to age compositions for School Whiting trawl onboard (retained).



Apx Figure A.34 Implied fits to age compositions for School Whiting trawl onboard (discarded).

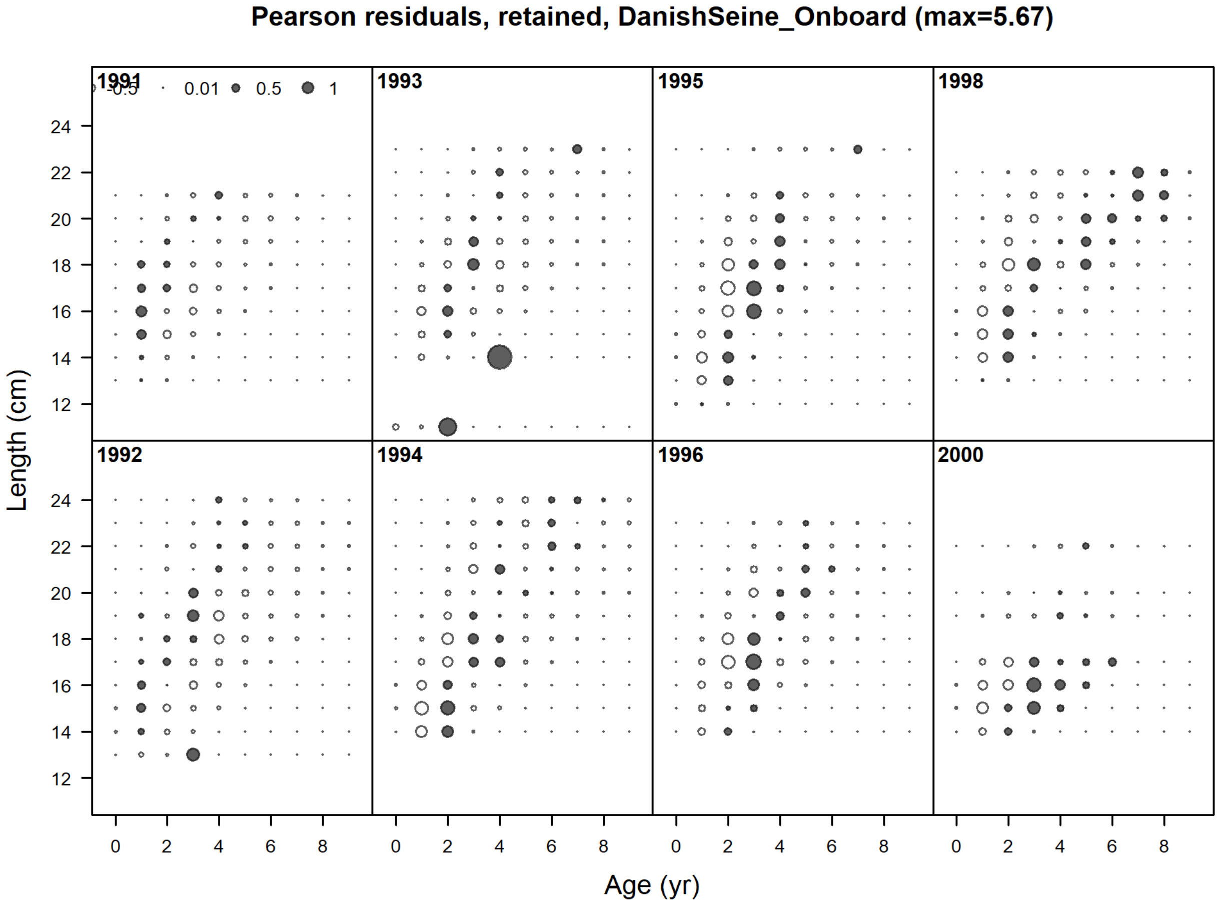


Apx Figure A.35 Implied fits to age compositions for School Whiting trawl port (retained).

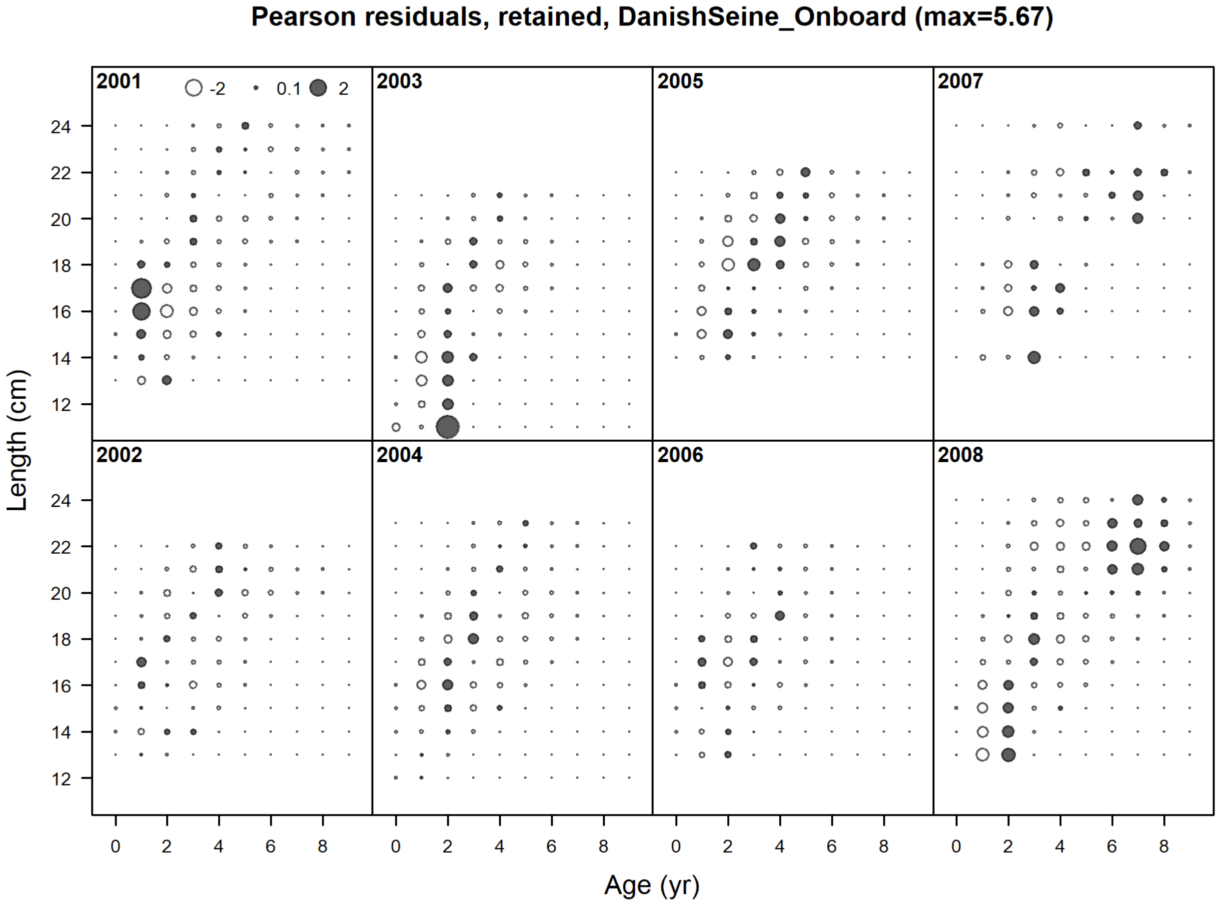


Apx Figure A.36 Implied fits to age compositions for School Whiting trawl port (discarded).

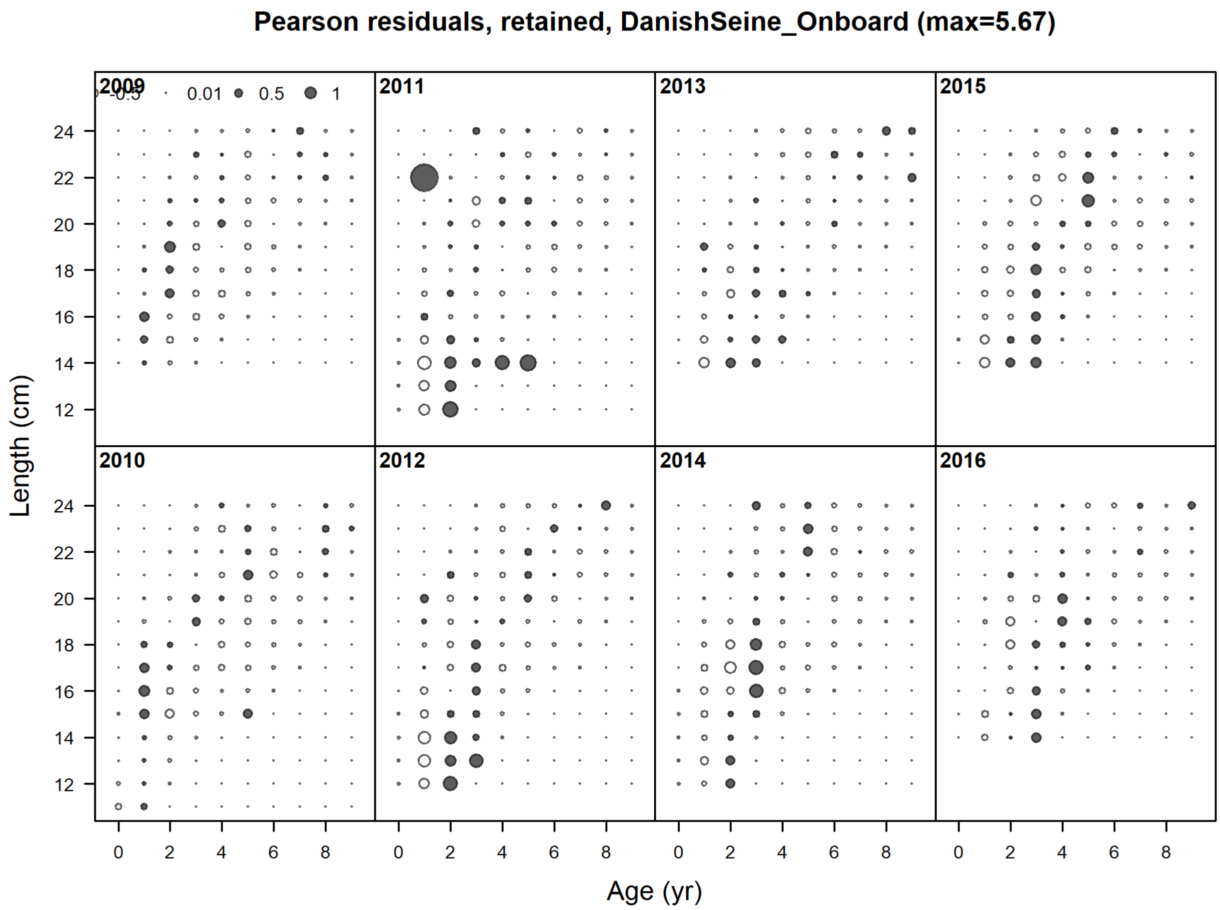
.



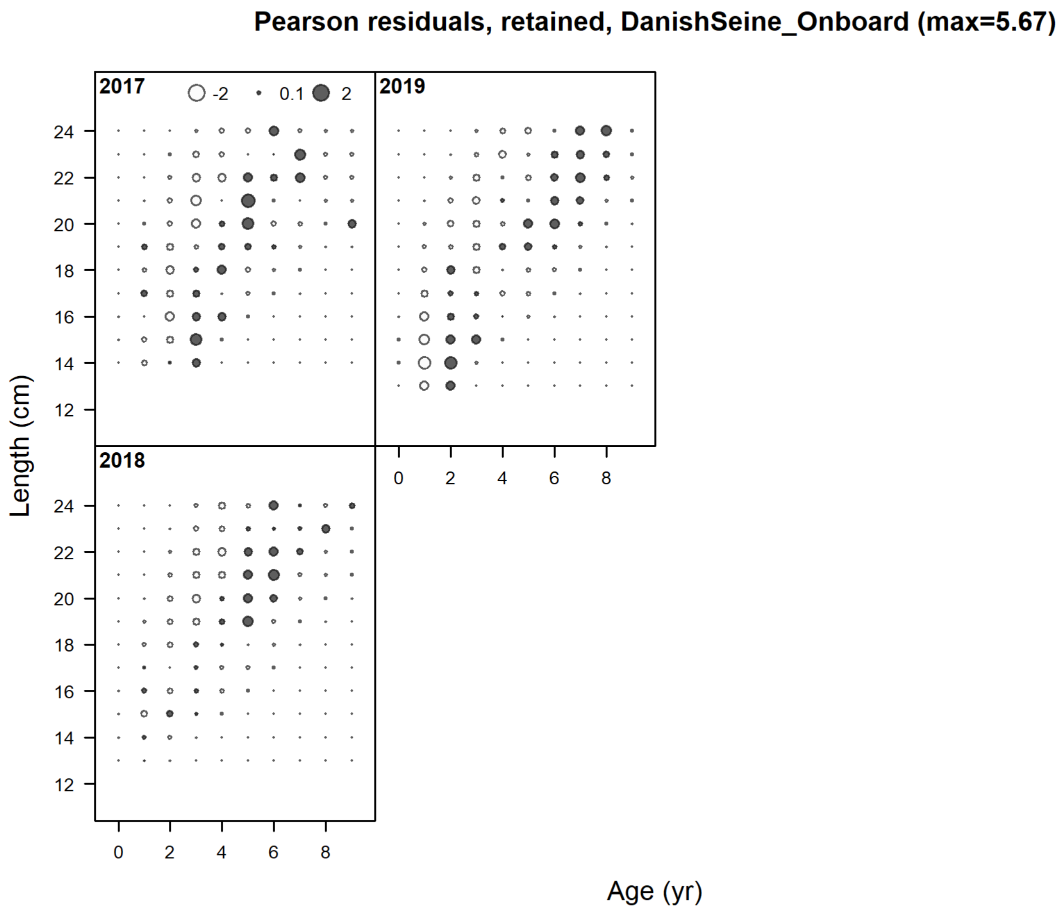
Apx Figure A.37 Residuals from the fits to conditional age-at-length for Danish seine 1991 to 2000. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.



Apx Figure A.38 Residuals from the fits to conditional age-at-length for Danish seine 2001 to 2008. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.

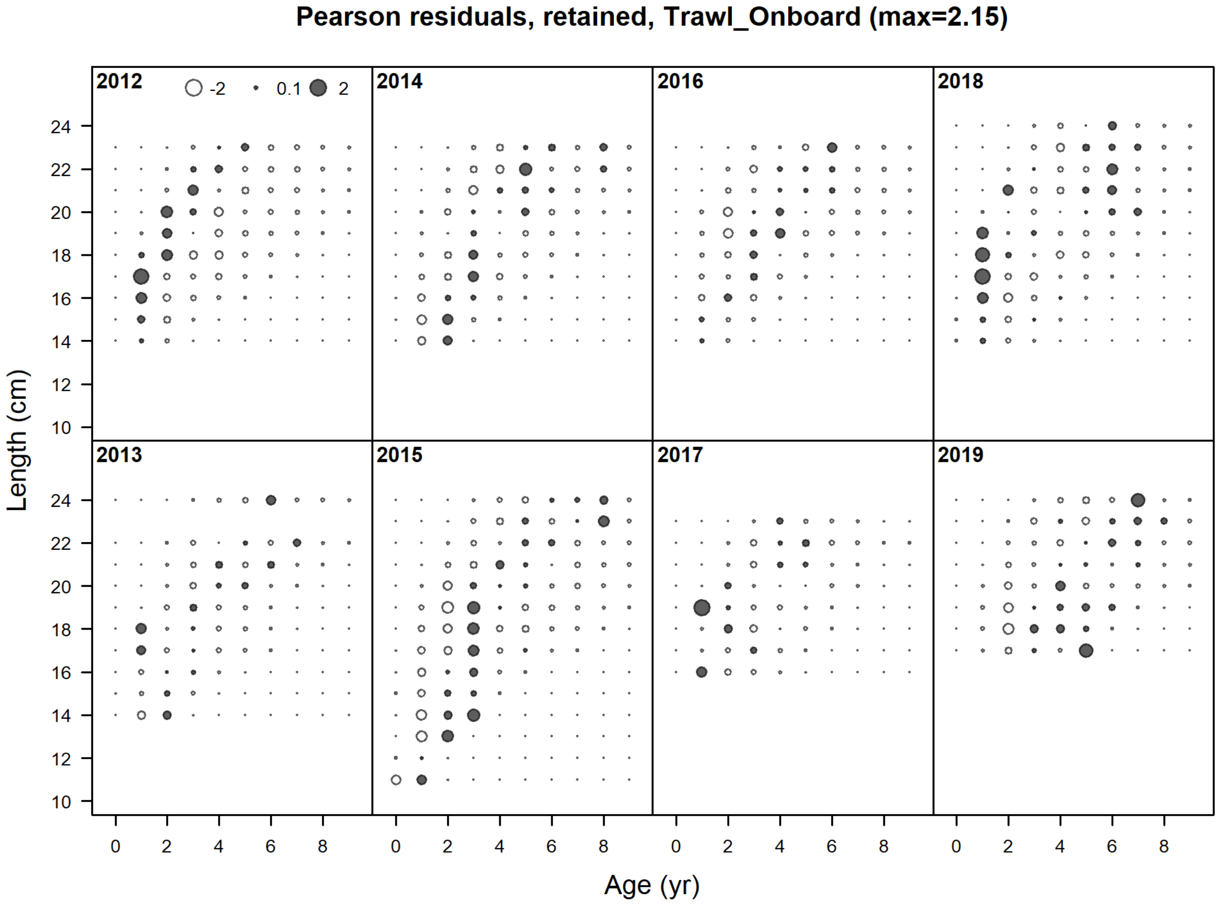


Apx Figure A.39 Residuals from the fits to conditional age-at-length for Danish seine 2009 to 2016. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.

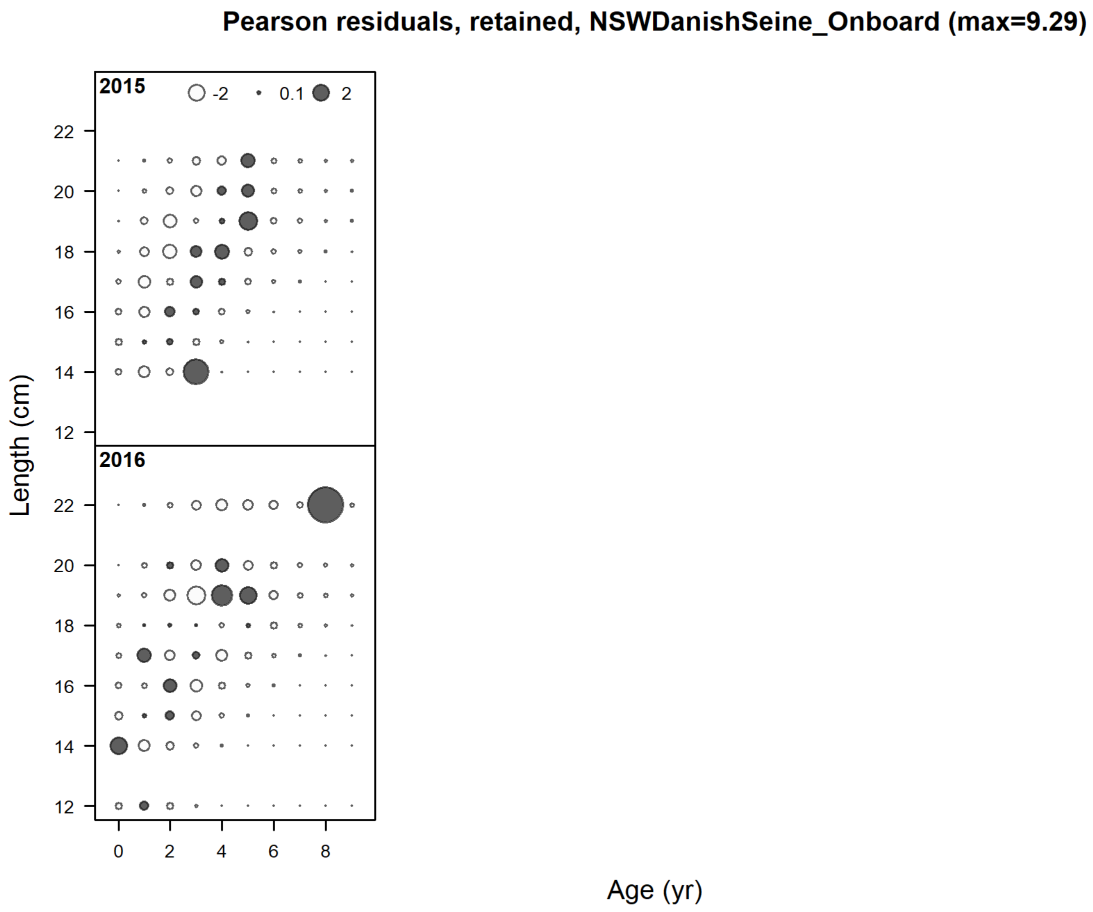


Apx Figure A.40 Residuals from the fits to conditional age-at-length for Danish seine 2017 to 2019. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.

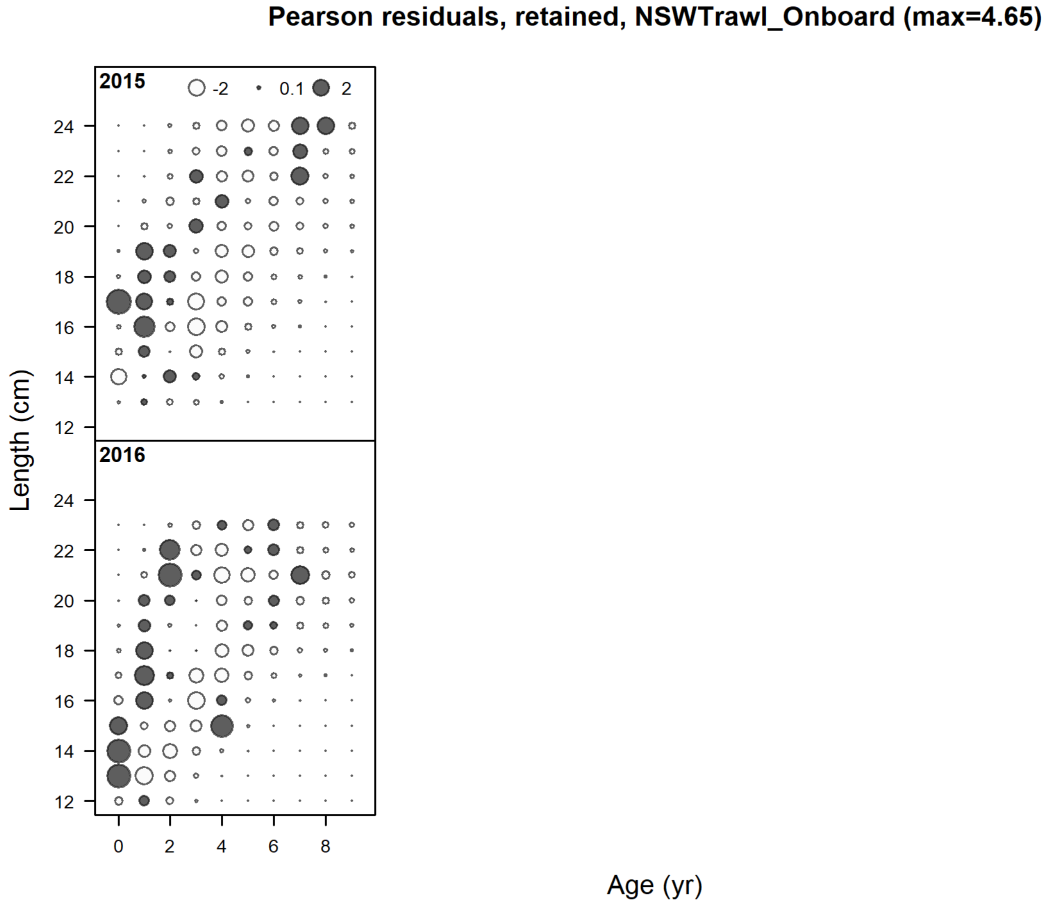
Apx Figure A.41 Residuals from the fits to conditional age-at-length for trawl 2001 to 2011. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.



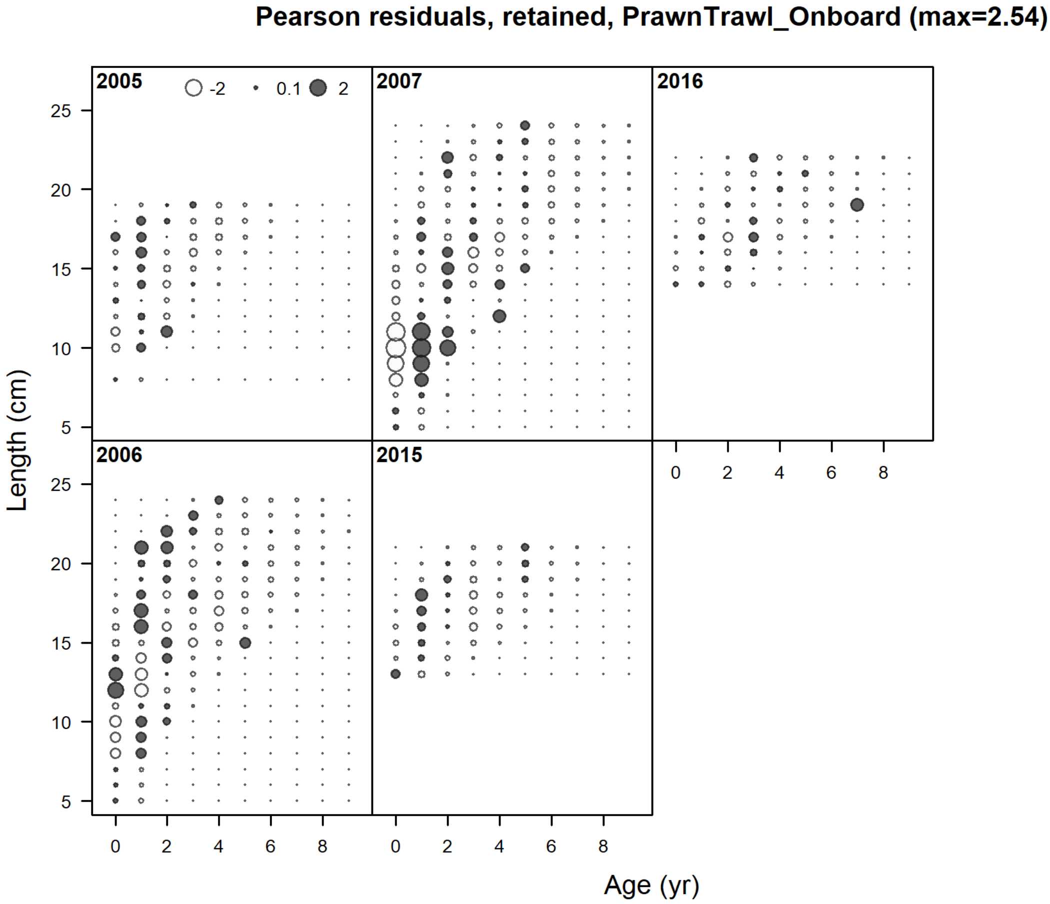
Apx Figure A.42 Residuals from the fits to conditional age-at-length for trawl 2012 to 2019. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.



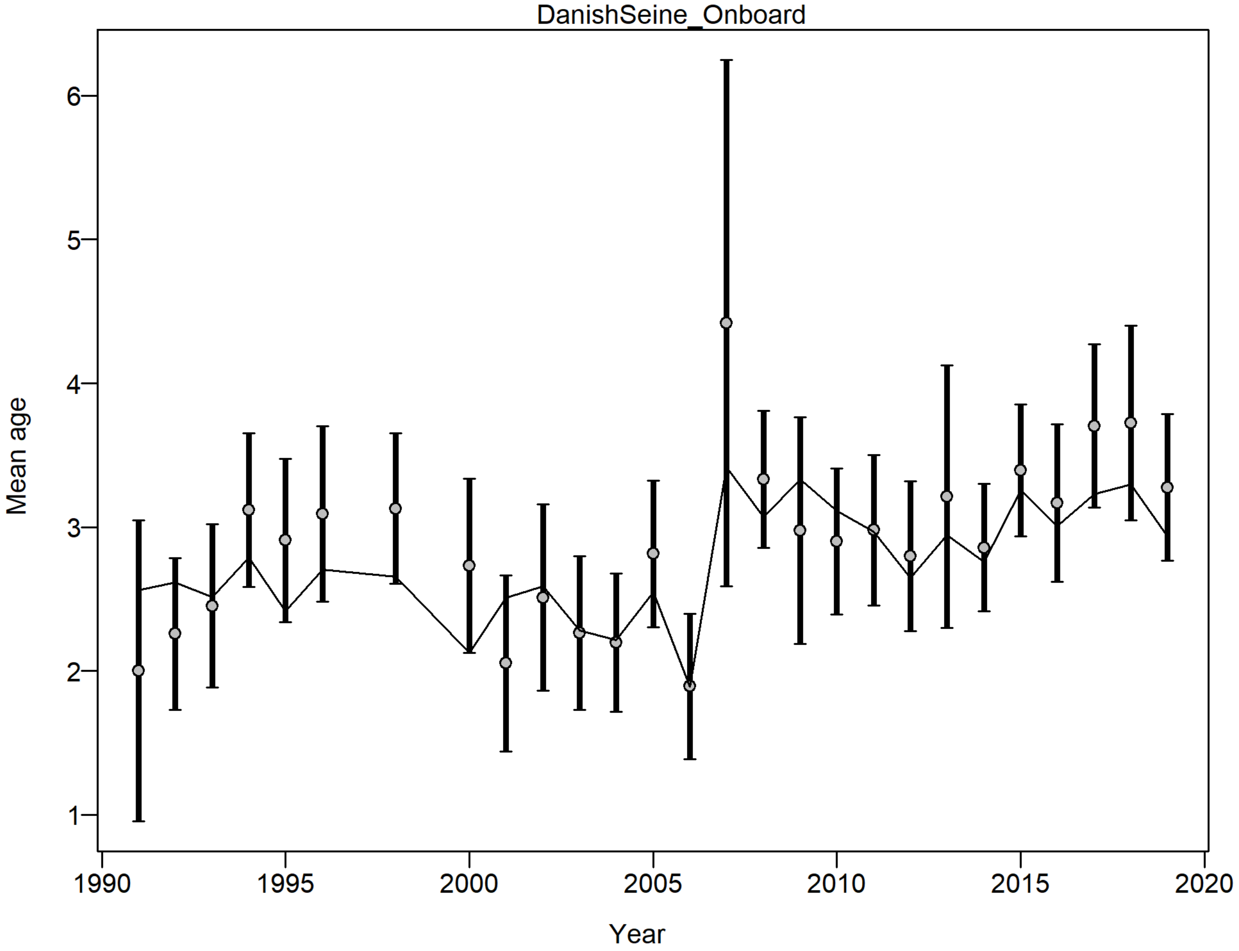
Apx Figure A.43 Residuals from the fits to conditional age-at-length for NSW Danish seine 2015 to 2016. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.



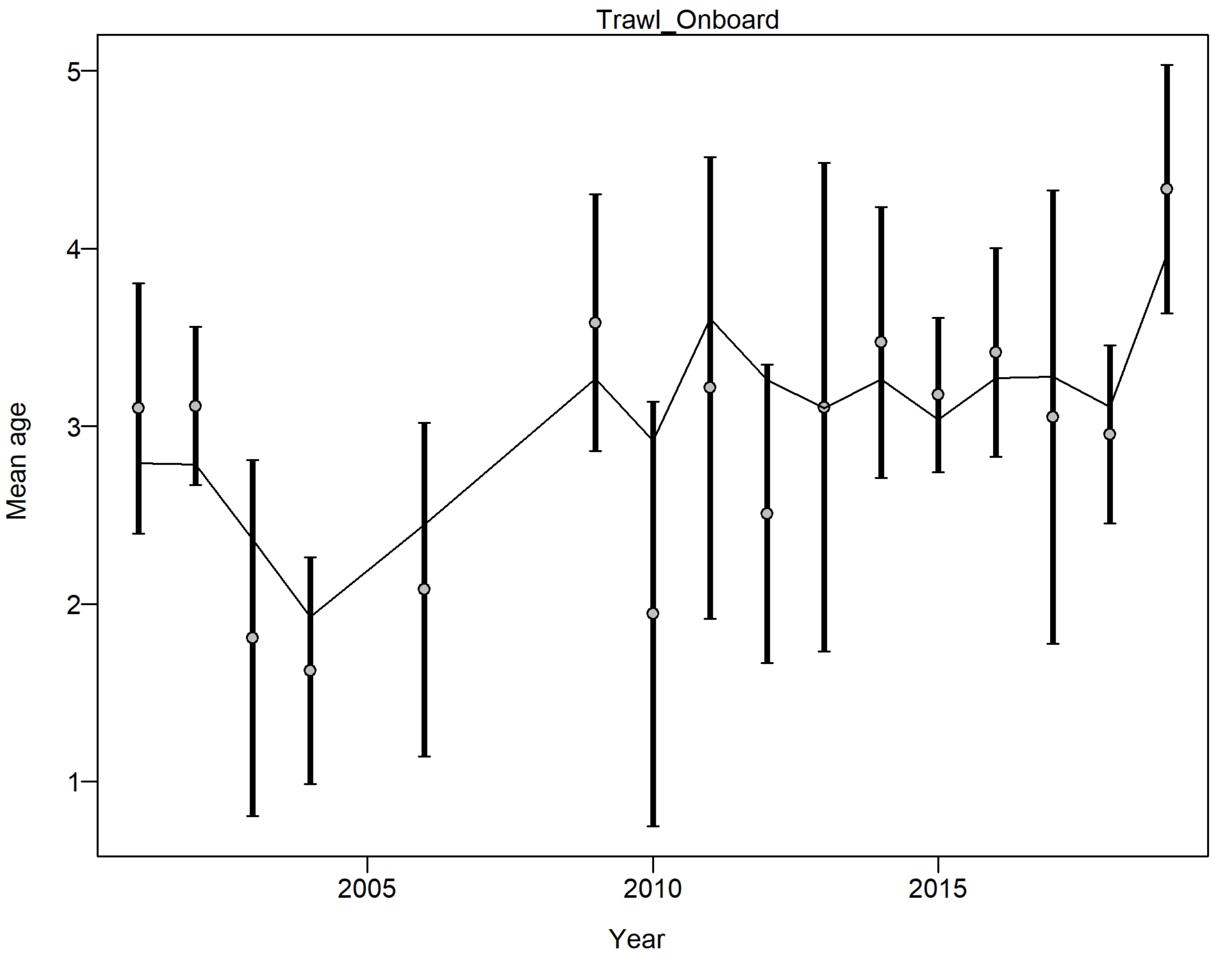
Apx Figure A.44 Residuals from the fits to conditional age-at-length for NSW trawl 2015 to 2016. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.



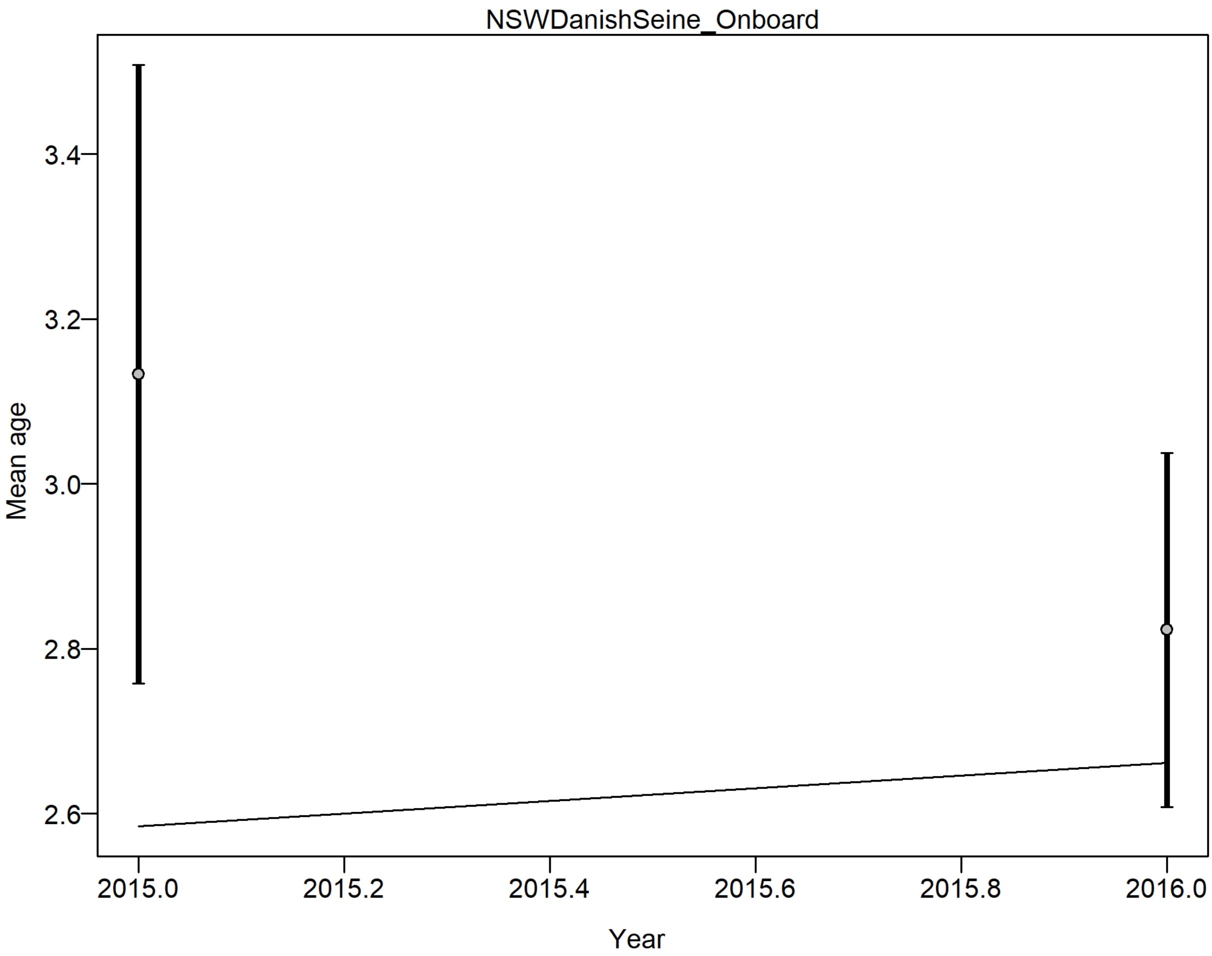
Apx Figure A.45 Residuals from the fits to conditional age-at-length for prawn trawl 2005 to 2016. This plot gives an indication of the variability in the conditional age-at-length samples from year to year.



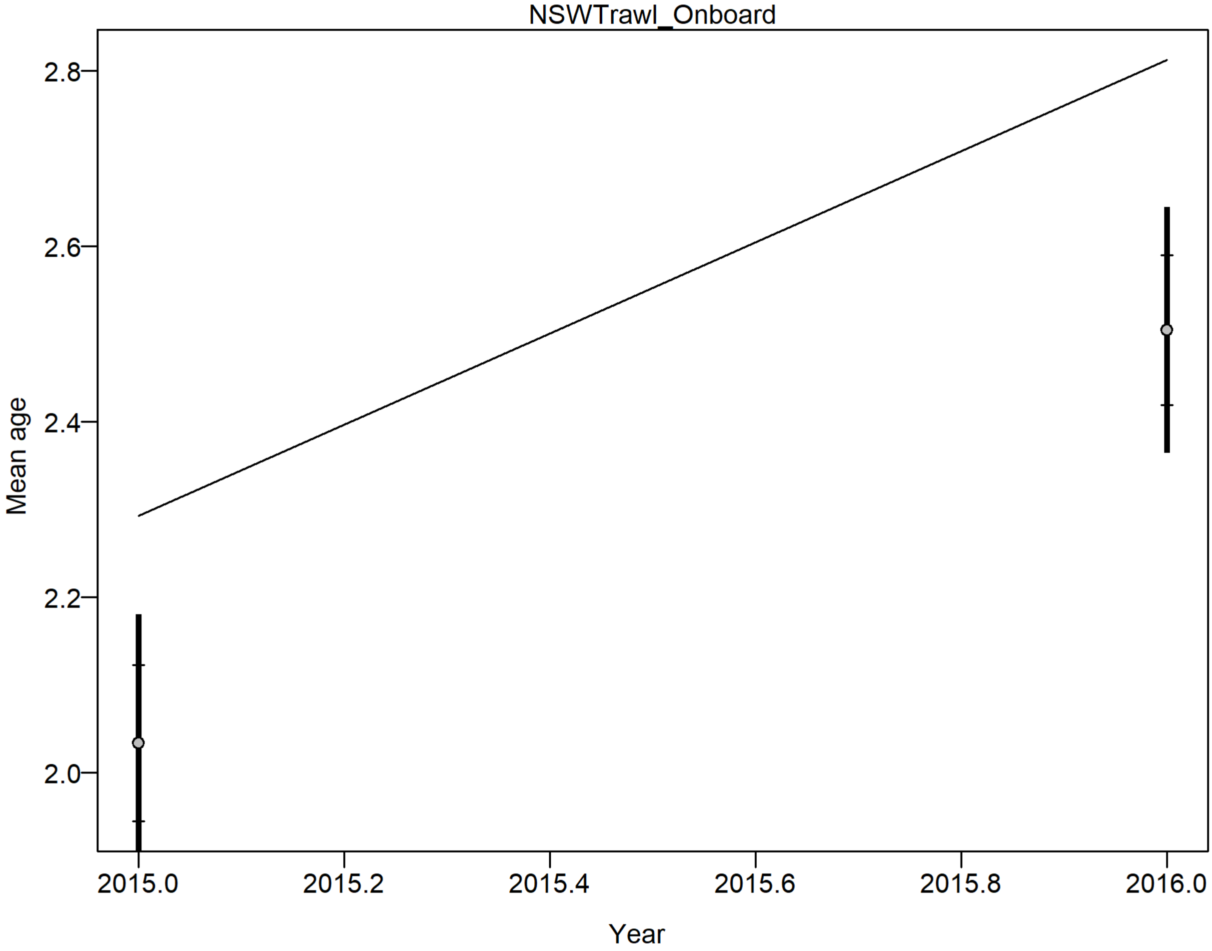
Apx Figure A.46 Mean age (aggregated across length bins) for School Whiting from Victorian Danish seine with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period (e.g. 2005-2007).



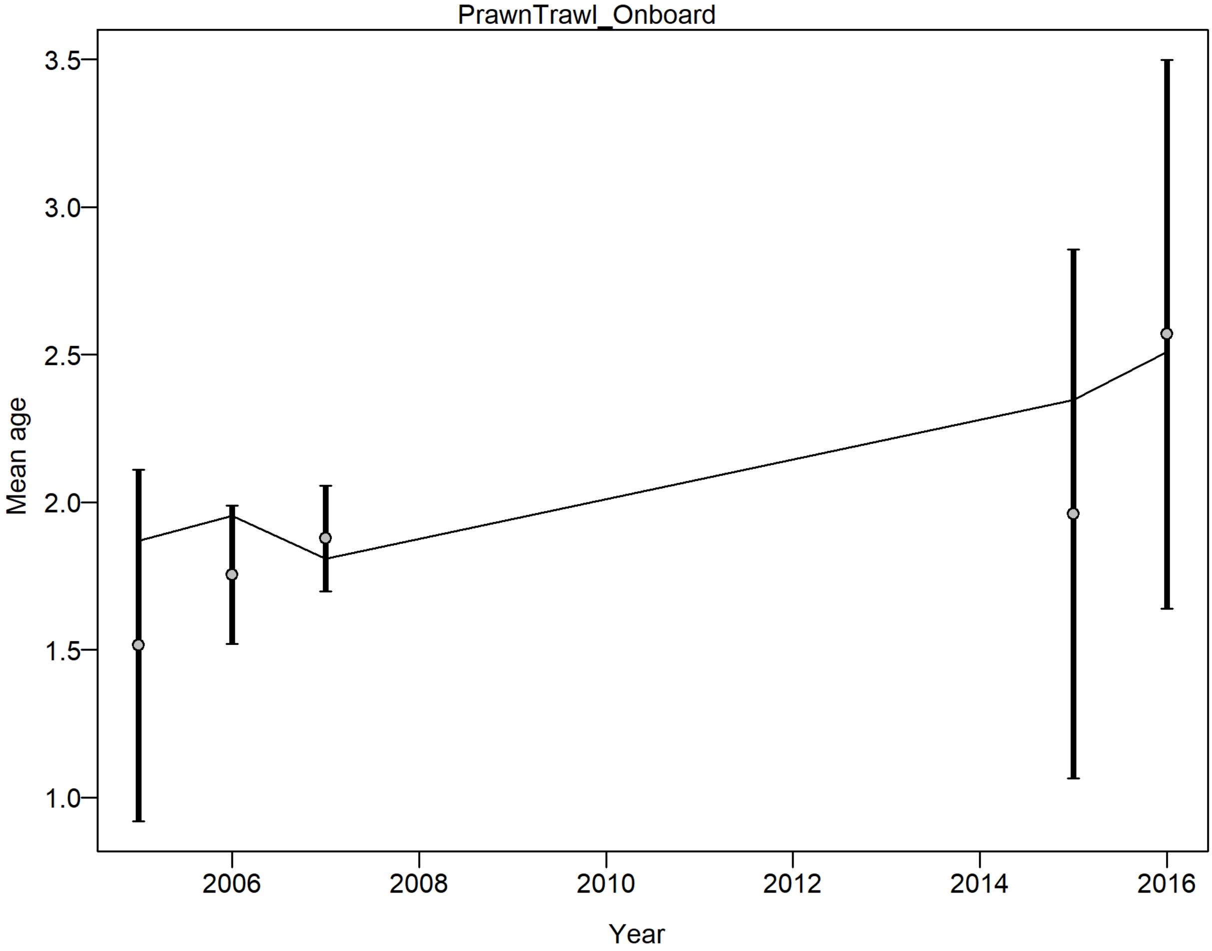
Apx Figure A.47 Mean age (aggregated across length bins) for School Whiting from trawl with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period (e.g. 2009-2011).



Apx Figure A.48 Mean age (aggregated across length bins) for School Whiting from NSW Danish seine with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.



Apx Figure A.49 Mean age (aggregated across length bins) for School Whiting from NSW trawl with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines which do not match thick lines indicate this is not well balanced, as the data weighting suggested upweighting to greater than the actual number of samples, so this was unable to be tuned.



Apx Figure A.50 Mean age (aggregated across length bins) for School Whiting from NSW prawn trawl with 95% confidence intervals based on current samples sizes. Punt data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

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. pp 374 - 414 *in* Tuck, G.N. (ed.) 2007. *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007.* Vol 2, 2007. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 584p.

Day J 2008a. Modified breakpoint for the 2008 Tier 1 harvest control rule. pp 153 -157 *in* Tuck, G.N. (ed.) 2009. *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2008.* Part 1. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 344p.

Day J 2008b. School Whiting (*Sillago flindersi*) stock assessment based on data up to 2007. pp 252 - 295 *in* Tuck, G.N. (ed.) 2009. *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2008.* Part 2. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 331p.

Day J 2009. School Whiting (*Sillago flindersi*) stock assessment based on data up to 2008. pp 190 - 249 *in* Tuck, G.N. (ed.) 2010. *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2008.* Part 1. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 334p.

Day J 2017. School Whiting (*Sillago flindersi*) stock assessment based on data to 2016. pp 588 -663 *in* Tuck, G.N. (ed.) 2018. *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2016 and 2017.* Part 2, 2017. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere, Hobart. 837p.

Day J, Hall K, Bessell-Browne P and Sporcic M 2020. School Whiting (*Sillago flindersi*) stock assessment based on data to 2019 – development of a preliminary base case. Unpublished report to SERAG. 62 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.

Francis RICC 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. **68**: 1124–1138.

Gray CA, Barnes LM, van der Meulen DE, Kendall BW, Ochwada-Doyle FA and Robbins WD 2014a. Depth interactions and reproductive ecology of sympatric Sillaginidae: *Sillago robusta* and *S. flindersi*. Aquatic Biology, **21**: 127-142.

Gray CA, Barnes LM, van der Meulen DE, Kendall BW, Ochwada-Doyle FA and Robbins WD 2014b. Age, growth and demographic characterisatics of *Sillago flindersi* Exploited in a multi-species trawl fishery. Fish Sci,80: 915-924.

Hall KC 2021. Stock status and assessment report 2020 – Ocean Trawl Fishery (Inshore Prawn, Offshore Prawn, Deepwater Prawn and Northern Fish Trawl) – Eastern School Whiting and Stout Whiting (*Sillago flindersi* and *Sillago robusta*). NSW Department of Primary Industries, Coffs Harbour, NSW.

Hobday D 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 and total mortality estimates for selected shelf and slope species in the South East Fishery. pp 12 -58 *in* Tuck, G.N. (ed.) 2006. *Stock Assessment for the Southern and Eastern Scalefish and SharkFishery 20005-2006.* Part 2, 2017. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 292p.

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

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.

Methot RD and Taylor IG 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment models. Can. J. Fish. Aquat. Sci. **68**: 1744–1760.

Methot RD Wetzel CR Taylor IG and Doering K 2020. Stock Synthesis User Manual Version 3.30.16. NOAA Fisheries, Seattle, WA USA. 225pp.

Pacific Fishery Management Council. 2018. Terms of Reference for the Groundfish and Coastal Pelagic Species Stock Assessment Review Process for 2017-2018 http://www.pcouncil.org/wp-content/uploads/2017/01/Stock_Assessment_ToR_2017-18.pdf.

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 2017. Some insights into data weighting in integrated stock assessments. Fish. Res. **192**: 52-65.

Punt AE. 2018. On the Use of Likelihood Profiles in Fisheries Stock Assessment. Technical paper for SESSFRAG, August 2018.

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.

Sporcic M 2020a. Draft Executive Summary: Statistical CPUE standardizations for selected SESSF species (data to 2019). CSIRO Oceans and Atmosphere, Hobart. Unpublished report to SESSFRAG Data Meeting. 13 pp.

Sporcic M 2020b. Draft statistical CPUE standardizations for selected SESSF Species (data to 2019). CSIRO Oceans and Atmosphere, Hobart. Unpublished report to SESSFRAG Data Meeting. 333 pp.

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.

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

AT CSIRO WE SHAPE THE FUTURE

We do this by using science to solve real issues. Our research makes a difference to industry, people and the planet.

As Australia's national science agency we've been pushing the edge of what's possible for over 85 years. Today we have more than 5,000 talented people working out of 50-plus centres in Australia and internationally. Our people work closely with industry and communities to leave a lasting legacy. Collectively, our innovation and excellence places us in the top ten applied research agencies in the world.

WE ASK, WE SEEK AND WE SOLVE

FOR FURTHER INFORMATION

CSIRO Oceans and Atmosphere
Jemery Day
t +61 3 6232 5296
e jemery.day@csiro.au
w http://www.csiro.au/en/Research/OandA