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# Redfish (*Centroberyx affinis*) stock assessment based on data up to 2019

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# Executive summary

This document describes the base case assessment and some of the issues encountered during the development of the quantitative Tier 1 Eastern Redfish (*Centroberyx affinis*) assessment in 2020. The last full assessment was presented in 2017 (Tuck and Day, 2017; Tuck et al., 2017). A preliminary base case was presented at the October 2020 RAG and was updated from the 2017 assessment by including data up to the end of 2019, which entails an additional 3 years of catch, discard, CPUE, length and age data and ageing error updates since the 2017 assessment.

Differences between port and onboard fish lengths were apparent in the 2017 assessment and resulted in estimation of different selectivity parameters for these datasets (Tuck et al. 2017). The assessment noted distinct differences between Eastern Bass (EBass) and New South Wales (NSW) port lengths. EBass port lengths are considerably larger than NSW port lengths, with ascending limbs beginning at ~10cm for NSW and ~15-20cm for EBass (Tuck et al. 2017, Bessell-Browne and Tuck 2020). This appears to be driven by different discard practices, as the distribution of retained fish lengths from the onboard length data are similar for EBass and NSW. Due to these differences, Tuck et al. (2017) suggested that future assessments should split data between these two regions, with this agreed as the new base case at the October 2020 RAG.

A base case assessment was achieved according to the RAG-agreed model structure that separated data by zone, with separate fleets in NSW (Zone 10) and EBass (Zones 20 and 30). The model fits one selectivity function for both fleets, but separate retention functions to allow for differences in discarding practices between the two areas. In addition to this spatial change, the base case now estimates natural mortality within the model rather than fixing this parameter.

The model fits to the length data and conditional age-at-length data reasonably well. Fits to catch rate data are reasonable but observed catch rates are overestimated in recent years. Estimates of recruitment since the early 2000s have been lower than average (except for 2011, 2012), potentially because of directional environmental change influencing productivity. Between 2000 and 2010, recruitment was on a downward trajectory (except 2007), but since 2010 recruitment appears to have been on an upward trajectory and is approaching close to average levels.

Due to this increasing trend in recruitment, the average recruitment used for low recruitment projection scenarios in this assessment were higher than used previously (Tuck et a. 2017). The low recruitment scenarios using average historical recruitment residuals over the past 10 years and constant annual catches of 50t showed an increase in spawning biomass to the limit refence point by 2039. Catches of 100t resulted in an increase in spawning biomass to the limit reference point by 2042, while catches of 150t took until 2047.

The assessment estimates that the projected 2021 spawning stock biomass will be 3.81% of unfished spawning stock biomass (projected assuming 2019 catches in 2020), compared to 7.72% at the start of 2018 from the last assessment (Tuck et. al., 2017). The reduction in estimated stock status since the 2017 assessment is likely due to continued flat or reduced catch rates since 2017 and no evidence of strong recruitment, along with lower estimation of natural mortality.

# 1 Introduction

## 1.1 The Fishery

Redfish are endemic to south-eastern Australian waters and are caught mainly on the continental shelf and upper slope waters from northern NSW to Tasmania and through Bass Strait.

The majority of the fishery operates in the waters of the southern coast of NSW (Rowling, 1994). Adult fish are mainly caught in continental slope waters to 450m, with most catch taken in trawls between 100-200m depth (Kaiola et al., 1993; Rowling, 1994).

An overview of the history of the fishery is included in Wise and Thomson (2002), along with Tuck and Day (2014), and is summarised below.

Redfish have been caught commercially in the south eastern region of Australia since the development of the trawl fishery in 1915. Most early Redfish harvests from 1915 were discarded as the fleet predominantly targeted Tiger Flathead (Houston 1955). The late 1950s and 1960s generally had small catches of Redfish as the fleet transitioned from steam trawlers to Danish seiners, although during the 1960s these Danish seine vessels transitioned again to otter trawling, with modern diesel trawlers common by the mid 1970s.

During expansion to the upper continental slope (to 600m depth), large incidental catches of Redfish were taken while targeting Gemfish. These Redfish caught in deeper water were generally larger and had increased market acceptance, with some targeted fishing occurring on either side of the main Gemfish season, although a large proportion of the catch were still discarded at sea due to oversupply of markets.

The supply of Redfish to the Sydney Fish Markets increased to 2400t in 1980 during a period of increased effort corresponding with increased market acceptance. The total catch of Redfish ranged between 1500 and 2000t each year until 1985, although by 1989 catches had decreased to 1000t, before increasing to 2000t in 1993.

In 1992 Individual transferable quotas were introduced, with a total allowable catch (TAC) set at 600t due to concerns of declining stock size from decreased catches and early stock assessments. During this period catches increased, resulting in an increase of the TAC to 1000t in 1994 and 1700t in 1995. This period was also characterised with the implementation of the Commonwealth fishery and there was reporting of harvest in NSW to avoid the low Commonwealth TAC. For example, in 1993 the TAC was 600t, although total landings were 2000t. This problem was overcome in 1994 when catches in NSW state waters south of Barrenjoey Point were restricted to 100kg of Redfish per trip.

From 1995 a decline in both catches and catch rates was observed, raising further concerns of the sustainability of the fishery. In 2000 the TAC was at an all-time high of 2,100t, before dropping consistently over the next 13 years. During this time, catches were well below the TAC and concerns for the sustainability of the stock were apparent.

The stock assessment conducted in 2014 suggested the stock size was 11.7% of unfished biomass in 2015 and was therefore below the limit reference point (Tuck and Day, 2014). This led to the development of the Redfish Stock Rebuilding Strategy and the introduction of a 100t incidental catch TAC between 2013/14 and 2018/19 fishing seasons, although this was always under caught. The incidental TAC was reduced in 2019/20 to 50t as there was no evidence of recovery of the stock and ongoing below average recruitment.

## 1.2 Previous Assessments

The first assessment of Redfish was completed in 1993 and concluded that the stock biomass was less than 20% of the unfished levels in the late 1980s, but increased catch and CPUE between 1990 and 1993 suggested increased recruitment (Chesson, 1995).

Further concerns for the stock led to the development of the Redfish Assessment Group in 1997 to determine and develop datasets representative of the fishery before the development of a base case stock assessment.

The first integrated assessment was completed by Thomson (2002) using ADMB and included data to 2001. The model separated regions between the north and south 36˚S. The results showed a large decline in biomass to approximately 25% of unfished spawning stock biomass in both northern and southern regions (Thomson, 2002). Concerns regarding fits to length data were made as the model tended to overestimate lengths before 1995 and underestimate them in the following period (Thomson 2002).

Klaer (2005) completed the next assessment, using the same data and biological assumptions as Thomson (2002) but with data updated to 2004. The assessment was completed using the Coleraine software package (Hilborn et al., 2000). The results from this assessment suggested that the stock size in both southern and northern regions was below 20% of unfished spawning stock biomass (Klaer, 2005).

The next assessment was completed by Tuck and Day (2014) and included data to 2013. This assessment used Stock Synthesis (version 3.24f), allowing for improved estimation of length-based selectivity that was not possible in previous assessments. The two-region structure of the assessment was not used, instead one stock was assumed between the north and south (Tuck and Day 2014). This assessment estimated the spawning stock biomass was 12% of unfished levels in 2015, well below the 20% limit reference point.

Tuck et al. (2017) completed the most recent assessment, using data to 2016. The model used the same structure as the 2014 assessment, although different selectivity patterns were estimated for port and onboard data. The model estimated the spawning stock biomass was 7.76% of the unfished levels and had further declined from previous assessments (Tuck et al., 2017). The assessment discovered differences between length frequency distributions between NSW and Eastern Bass Strait (EBass) regions and suggested future assessments should consider a regional split in the model, to allow separate retention functions to be fit for each region.

## 1.3 Modifications to the previous assessment

This assessment uses the current version of Stock Synthesis, SS-V3.30.16.00 (Methot et al., 2020). The number of growth parameters estimated and assumptions about early catch and discarding rates in this assessment are identical to the 2017 assessment (Tuck et al., 2017). Four growth parameters are estimated for both males and females (CV, $K$, $l_{max}$ and $l_{min}$).

The previous assessment estimated two selectivity patterns, one for onboard data and another for port, with one retention function (Tuck et al., 2017). The new model structure only estimates one selectivity pattern for both NSW and EBass. It also now estimates two retention functions, one for each region to allow for differences in discard practices between each region, which is assumed to be the cause of the different length distributions across regions.

Previous base case assessments have fixed natural mortality at 0.1 year$^{-1}$, however likelihood profiles suggested this value was outside the 95% confidence intervals, with the model suggesting lower values of natural mortality provided better fits to data in the model (Bessell-Browne and Tuck, 2020). Further investigations revealed the model was able to estimate natural mortality and this was agreed to be included as the new base case in the October RAG 2020.

Updates to data used in the previous assessment have resulted from changes AFMA made to their observer database (affecting data for all years) and changes, improvements and corrections in the processing of data and filtering of records (Thomson et al., 2019). Changes in length structures and samples sizes are also apparent from the previous assessment. These changes are due to improvements in data processing prior to inclusion in the assessment.

The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be contributing to changes in the assessment outcome was conducted and is not presented here (Bessell-Browne and Tuck, 2020).

# 2 Methods

## 2.1 Model Structure

The 2020 preliminary base case assessment of Eastern Redfish uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.16.00, Methot et. al., 2020). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (*h*), the expected average recruitment in an unfished population ($R_0$), and the degree of variability about the stock-recruitment relationship ($\sigma_r$). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base–case model includes the following key features:

- A two-region, single-stock model is considered, utilising the fleets as region approach (Berger et al., 2012; Hurtado-Ferro et al., 2014; Waterhouse et al., 2014). Data is separated between NSW (Zone 10) and Eastern Bass Straight (EBASS, Zones 20 and 30). This new structure was agreed as the new base case in SERAG #1 2020, instead of the single region base case which has been the RAG agreed base-case since 2014.
- The selectivity pattern for the trawl fleets were assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment. One selectivity function was estimated across both regions, and also for both onboard and port samples.
- The model accounts for males and females separately.
- The initial and final years are 1975 and 2019. Previous models (Thomson, 2002; Klaer, 2005; Tuck, 2014; Tuck et. al., 2017) used 1975 as the initial year due to the generally perceived poorer quality of data prior to this year. An initial fishing mortality is estimated to account for catches prior to the starting year.
- The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.26; Sporcic, 2020), before being re-tuned to the model-estimated standard errors within SS.
- Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection point and slope of this function were estimated where discard information was available. A retention function was estimated for each ‘block’ period: namely 1975 – 1985 and 1986 – 2019. Separate retention functions were also estimated for each region to allow for different discarding practices between NSW and EBASS.

- Over the period 1975-1985 a logistic retention function is used with a cap less than 1.0 (i.e. larger fish do not reach full retention and can be discarded; fixed at 0.8; Tuck and Day, 2014).
- The rate of natural mortality, *M*, is assumed to be constant with age, and also time-invariant. The value for *M* is estimated within the model.
- Recruitment to the stock is assumed to follow a Beverton-Holt 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.
- The initial value of the parameter determining the magnitude of the process error in annual recruitment, $\sigma_R$, is set to 0.7.
- The population plus-group is modelled at age 40 years, as is the maximum age for observations.
- Growth is assumed to follow a von Bertalanffy length-at-age relationship, with the parameters of the growth function estimated separately for females and males inside the assessment model.
- Retained and discarded onboard length samples were only included if over 100 fish were sampled and the number of shots were included as the sampling unit. For Sydney Fish Market samples (1975 to 1991) numbers of fish were divided by 10 and capped at 200. For port samples, numbers of trips were used as the sampling unit, with a cap of 100 (which was not reached). The sample size is reduced because the appropriate sample size for length frequency data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 1.

**Table 1. Parameter values assumed for some of the non-estimated parameters of the base-case model.**

| Parameter | Description | Value |
|---|---|---|
| *h* | “steepness” of the Beverton-Holt stock-recruit curve | 0.75 |
| *x* | age observation plus group | 40 years |
| *a* | allometric length-weight equations | 0.0577 $g^{-1}$.cm |
| *b* | allometric length-weight equations | 2.77 |
| $l_m$ | Female length at 50% maturity | 19cm |

## 2.2 Data

Bessell-Browne and Tuck (2020) described the process of moving to the new version of Stock Synthesis (version SS-V3.30.16.00, Methot, 2020) and this is not repeated here. For completeness, the data inputs to the model are described. The data inputs to the assessment come from multiple sources: length and conditional age-at-length data from the trawl fishery, updated standardized CPUE series (Sporcic, 2020), the annual total mass landed and annual discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were separated between two regions, NSW (Zone 10) and Eastern Bass Straight (EBASS, Zones 20 and 30).

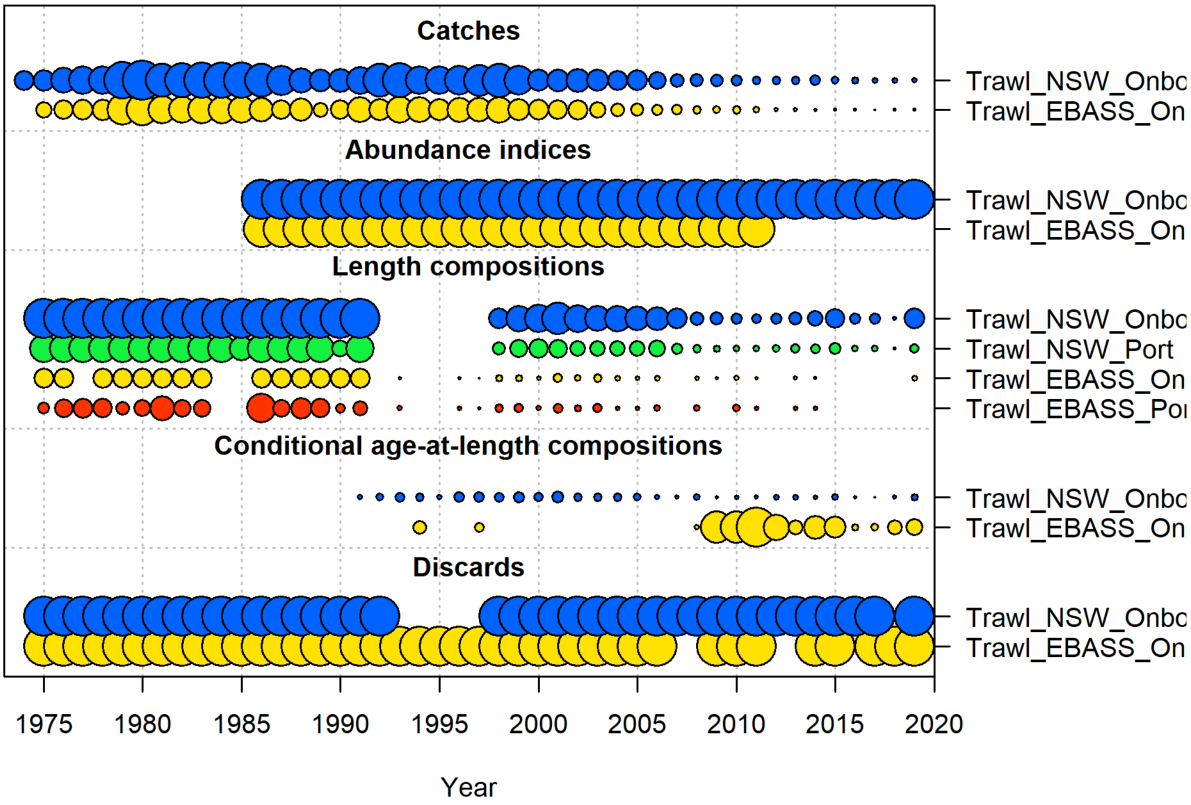



**Figure 1. Summary of data sources used in the 2020 base case Redfish assessment.**

### 2.2.1 Catch data

Total annual catches (t) for Redfish have been estimated based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and CPUE are provided in Table 2. Where available, previously agreed catch tonnages from RAGs were used (Rowling, 1999; Klaer, 2005). CDR records and NSW state catch data are used from 2005 for the base-case model. Table 2 shows the annual catch values used in the assessment, split by region. Figure 2 shows the total catch by region used in the assessment.

**Table 2. Estimated landings (t), discard rates and standardized CPUE (Sporcic, 2020) for Redfish by calendar year. Total catch (Commonwealth and state) for years 1975 to 2004 were taken from previously agreed catch estimates from redfish assessment group meetings (Rowling, 1999, Appendix 1; Klaer, 2005) and from CDR records for 2005 onwards.**

| Year | Landings (t) NSW | Landings (t) EBASS | Discard Rates NSW | Discard Rates EBASS | CPUE NSW | CPUE EBASS |
|---|---|---|---|---|---|---|
| 1975 | 451 | 249 | 0.400 | 0.400 | | |
| 1976 | 645 | 355 | 0.400 | 0.400 | | |
| 1977 | 774 | 426 | 0.400 | 0.400 | | |
| 1978 | 761 | 439 | 0.400 | 0.400 | | |
| 1979 | 1251 | 849 | 0.400 | 0.400 | | |
| 1980 | 1441 | 959 | 0.300 | 0.300 | | |
| 1981 | 990 | 710 | 0.200 | 0.200 | | |
| 1982 | 1105 | 695 | 0.200 | 0.200 | | |
| 1983 | 1238 | 762 | 0.200 | 0.200 | | |
| 1984 | 1265 | 735 | 0.200 | 0.200 | | |
| 1985 | 1279 | 721 | 0.200 | 0.200 | | |
| 1986 | 110 | 597 | 0.200 | 0.200 | 1.951 | 1.2303 |
| 1987 | 995 | 405 | 0.150 | 0.150 | 1.537 | 1.6285 |
| 1988 | 654 | 546 | 0.150 | 0.150 | 1.6348 | 2.1656 |
| 1989 | 567 | 233 | 0.150 | 0.150 | 1.3367 | 1.2865 |
| 1990 | 606 | 394 | 0.100 | 0.100 | 1.7738 | 1.5191 |
| 1991 | 840 | 760 | 0.100 | 0.100 | 1.8749 | 1.9794 |
| 1992 | 1263 | 537 | 0.25 | 0.250 | 2.5623 | 1.5222 |
| 1993 | 1297 | 803 | | 0.576 | 3.0787 | 1.8766 |
| 1994 | 871 | 729 | | 0.563 | 2.1386 | 1.7273 |
| 1995 | 877 | 522 | | 0.749 | 1.3918 | 1.1015 |
| 1996 | 871 | 629 | | 0.284 | 1.1906 | 1.1317 |
| 1997 | 1003 | 597 | | 0.063 | 1.3769 | 0.9352 |
| 1998 | 1128 | 672 | 0.059 | 0.482 | 1.6932 | 0.9769 |
| 1999 | 907 | 499 | 0.022 | 0.072 | 1.3601 | 0.8486 |
| 2000 | 442 | 393 | 0.073 | 0.251 | 0.9184 | 0.5745 |
| 2001 | 459 | 335 | 0.457 | 0.377 | 0.8753 | 0.5953 |
| 2002 | 523 | 357 | 0.534 | 0.638 | 0.7147 | 0.6854 |
| 2003 | 440 | 237 | 0.304 | 0.597 | 0.7122 | 0.4355 |
| 2004 | 366 | 172 | 0.428 | 0.376 | 0.5947 | 0.4425 |
| 2005 | 419 | 161 | 0.194 | 0.420 | 0.6062 | 0.57 |
| 2006 | 286 | 111 | 0.013 | 0.118 | 0.5783 | 0.4942 |
| 2007 | 177 | 107 | 0.417 | 0.800 | 0.5091 | 0.5765 |
| 2008 | 159 | 72 | 0.027 | 0.017 | 0.4806 | 0.4887 |
| 2009 | 148 | 61 | 0.192 | 0.045 | 0.3769 | 0.4956 |
| 2010 | 123 | 66 | 0.207 | 0.191 | 0.3633 | 0.4526 |
| 2011 | 73 | 42 | 0.112 | 0.173 | 0.2891 | 0.2598 |
| 2012 | 72 | 17 | 0.016 | 0.610 | 0.2383 | |
| 2013 | 71 | 12 | 0.262 | | 0.2891 | |
| 2014 | 100 | 12 | 0.399 | 0.380 | 0.411 | |
| 2015 | 63 | 8 | 0.430 | 0.765 | 0.2654 | |
| 2016 | 45 | 7 | 0.360 | | 0.22 | |
| 2017 | 33 | 3 | 0.289 | 0.576 | 0.2272 | |
| 2018 | 30 | 8 | | 0.563 | 0.1995 | |
| 2019 | 28 | 6 | 0.443 | 0.749 | 0.231 | |

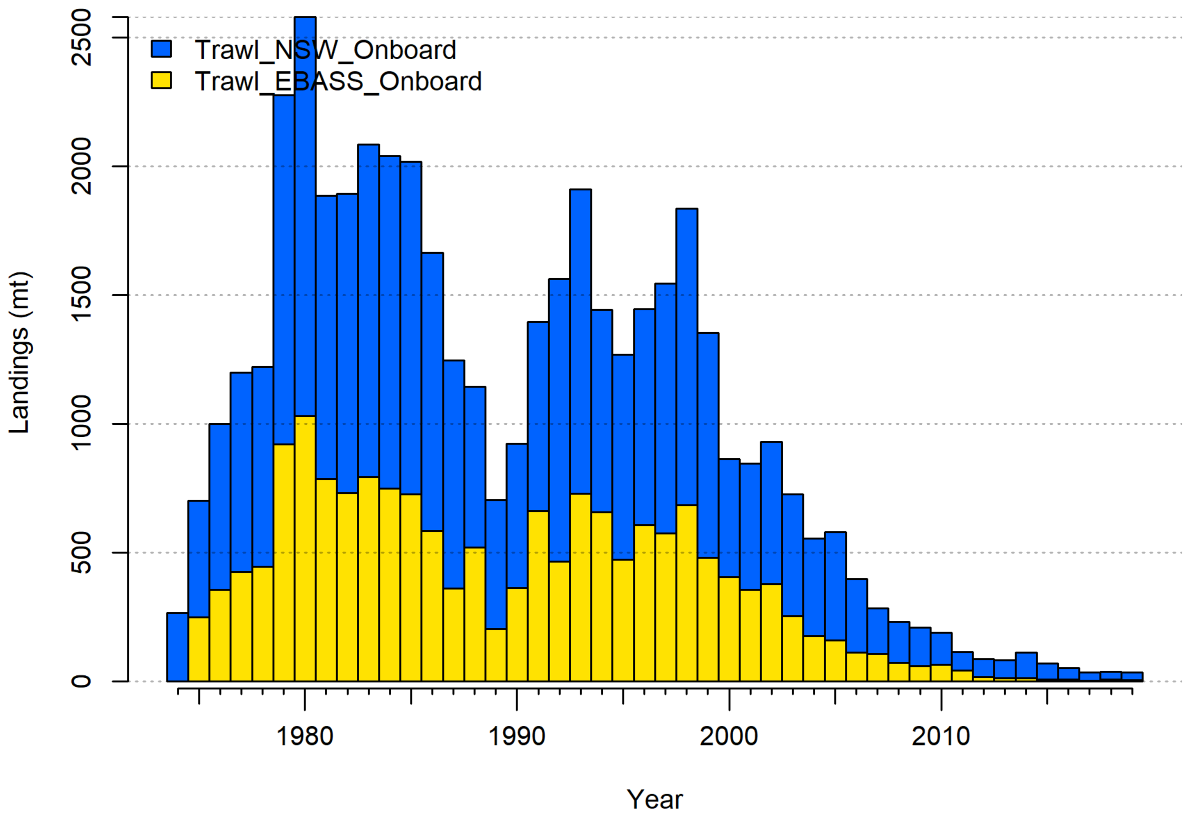



**Figure 2. A comparison of total landed catch by fleet for Redfish.**

### 2.2.2 Discard rates

Discard rates prior to 1992 are those estimated by the Redfish RAG (Rowling, 1999; Thomson, 2002). Discard rates after 1992 were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011). Rowling (1999) provides considerable detail on how the historical discard rates were estimated and the factors that influenced discard practices. Redfish discarding was discussed at a Redfish workshop held in Cronulla in April 1997 and at various open Redfish assessment group meetings during late 1997 and early 1998. The resulting discard rates are documented in Rowling (1999) and also listed in the Redfish assessment group (Thomson, 2002) and Shelf RAG (Klaer, 2005) assessments of Redfish. Here we update the discard estimates by including on-board estimates through to 2019 (Table 2).

The assessment model allows an estimation of the probability of retention (which is 1 – P(discard)) as a function of length in order to estimate the annual discard rate and any information on discard length composition. It is apparent that the Redfish fishery has undergone numerous changes that may have influenced the behaviour of discarding; these changes are documented in Rowling (1999; Appendix 2). In consultation with K. Rowling (pers. comm.), the following discarding periods have been identified:

**1975 – 1985. Market driven discarding**

1975 – 1985. Discards largely across all size ranges, but with more small fish discarded

**1986 – 2000. Surimi markets period**

1986 – 1992. Surimi market. Discarding rates lower, mainly small fish.

1993 – 1995. Quantity of fish sent to surimi market declined, Geelong surimi market closes; consequent increase in discarding.

1996 – 2000. Discarding declined 'as Redfish became less available'. Close of Hacker surimi processor in 2000.

**2001 – 2019. Size based discarding period**

2001 – 2019. Assume mostly small fish discarded

These changes in discarding behaviour have influenced the large variations in discard rates observed (Table 2), as well as the catches, catch rates and discard length composition. The RAG agreed (2014) base case model allows the retention function to vary according to the identified discard period from 1975 to 1985 (market driven), and from 1986 to 2019 (size driven). A separate retention function has been modelled for each region to allow for different discarding practices, with estimated model discards by region displayed in Figure 3.

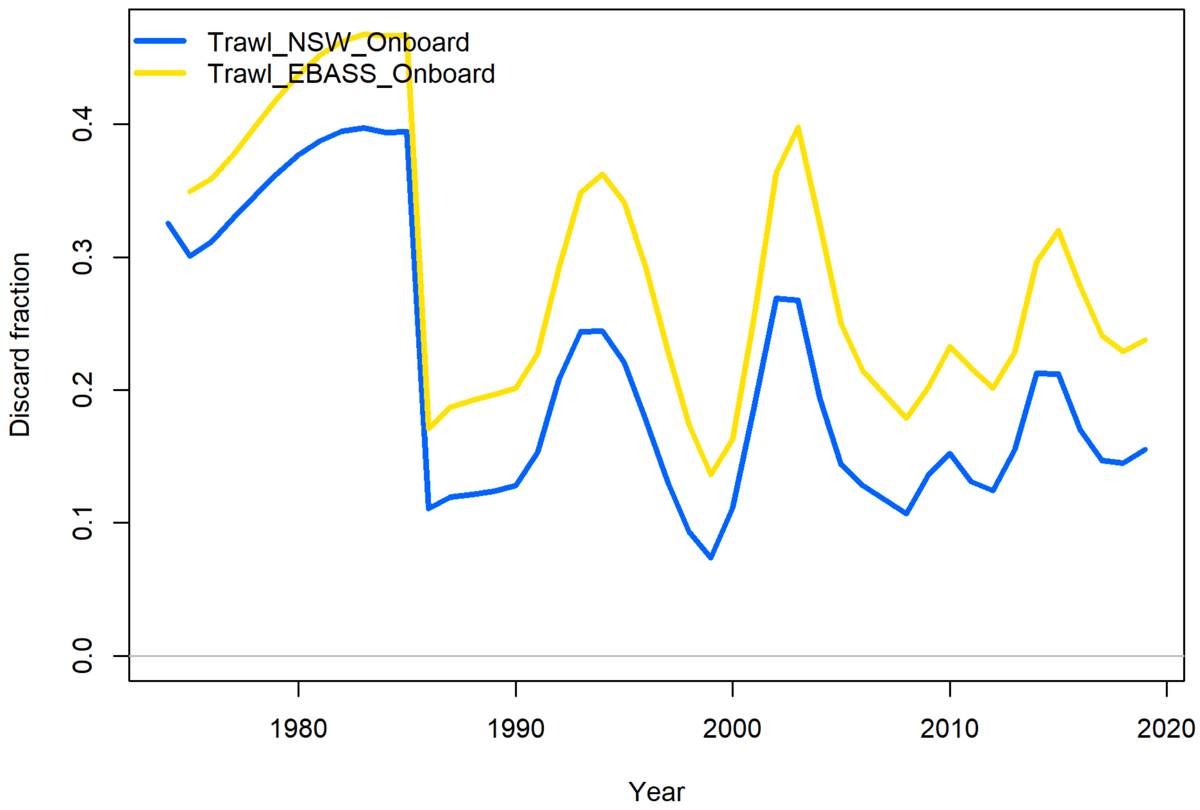



**Figure 3. Model estimated discard as a proportion of catch for Redfish by fleet.**

### 2.2.3 Catch rates

Sporcic (2020) provides the updated standardised catch rate series for Redfish (Table 2; Figure 4). Additional catch rate series were calculated, with separate analyses for both NSW and EBASS (pers. comm, Sporcic, 2020) and are displayed in Figure 4. Similar overall trends are apparent in the catch rates for both regions (Figure 4). After substantial increases in the NSW catch rate in the early and late 1990s, the NSW catch rate has declined, and is now less than 10% of 1986 levels (Figure 4). A short-lived increasing trend in the NSW catch rate occurred in 2014 but subsequent estimates have either declined or remained stable (Figure 4). In EBASS catch rates were variable from 1985 to 1995, although they were above the average of the timeseries (Figure 4). Since 1995 there has been a continued decline in EBASS catch rates, similar to those observed in NSW (Figure 4). Catch rates were not able to be calculated after 2011 in the EBASS as there was insufficient catch to inform estimates (Figure 4).

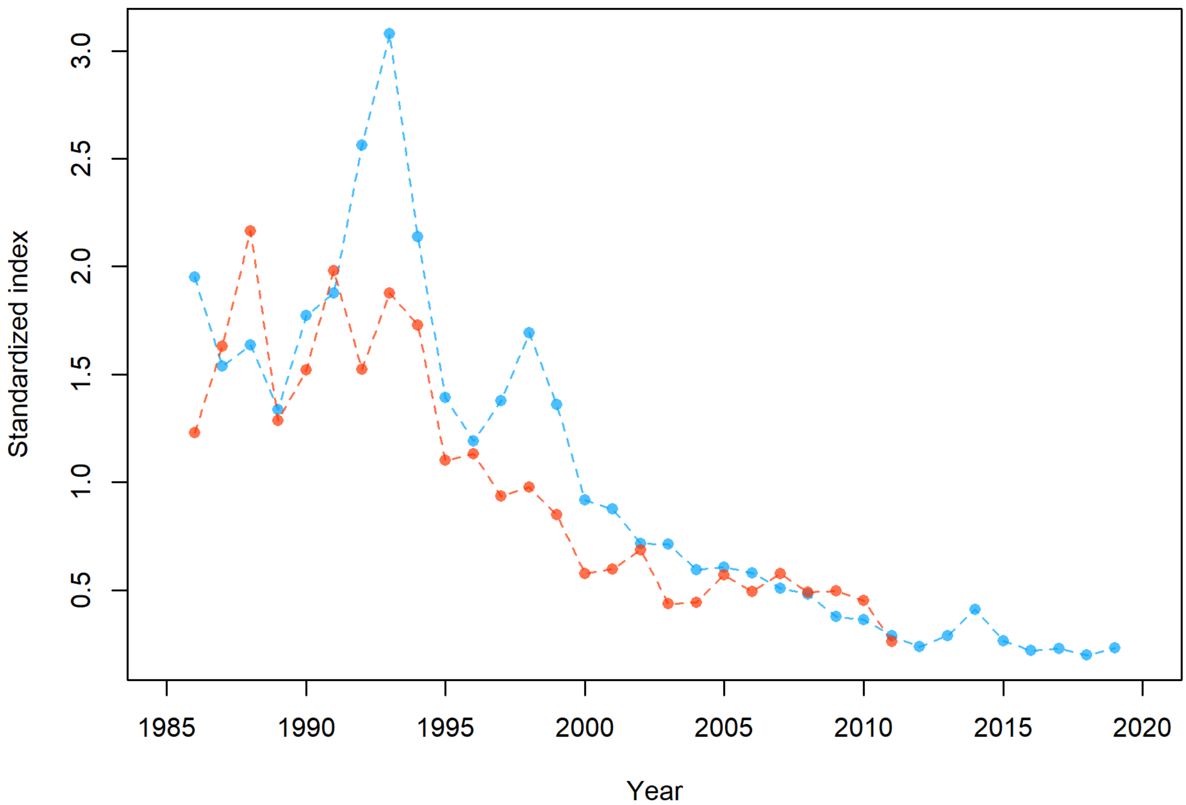



**Figure 4. A comparison of the annual catch rates series for redfish by region, NSW is depicted with the blue line and EBASS is the red line.**

### 2.2.4 Length frequencies and age data

Length and age data have been included in the model as length frequency data and conditional age-at-length data by year and sex (when available). Age composition data is included in diagnostic plots but is not used directly within the fitting procedure. Length frequency data were obtained from NSW records of fish measured at the Sydney Fish Markets to 1991. After 1991 length frequencies were obtained from the Integrated Scientific Monitoring Program (ISMP) on-board and port measurements. The observed length and age data are shown in later figures with the corresponding model predicted values. The Kapala length frequencies and Fishery Independent Survey (FIS) abundance indices are not included in the RAG agreed base-case model (Tuck and Day, 2014; Tuck et. al., 2017). The total number of annual length samples collected in relation to both the number of fish and number of shots or trips are displayed for both onboard (Table 3) and port data (Table 4). The number of otoliths collected for use in conditional age-at-length data and also age frequencies are displayed in Table 5.

### 2.2.5 Biological parameters and stock structure assumptions

The assessment assumes that length at 50% maturity is 19cm for females (Thomson, 2002). Natural mortality is estimated within the model. Steepness is assumed to be 0.75. Parameters for the length weight relationship were taken from Klaer (2005; also used by Thomson, 2002). Growth parameters, including the von Bertalanffy growth parameter *k*, are estimated. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and are split between NSW (zone 10) and EBASS (zones 20 and 30).

### 2.2.6 Age-reading error

Standard deviations for ageing error by reader have been estimated, producing the age-reading error matrix (Table 6, P. Burch, pers. comm.). Briefly, this calculation was estimated based on methodology developed by Richards et al. (1992) and Punt et al. (2008).

**Table 3. Number of onboard retained lengths and number of shots by fleet for length frequencies included in the base case assessment by fleet 1975-2019.**

| Year | Retained | | | | Discarded | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of fish | | Number of shots | | Number of fish | | Number of shots | |
| | NSW | EBASS | NSW | EBASS | NSW | EBASS | NSW | EBASS |
| 1975 | 7343 | 289 | 200 | 200 | | | | |
| 1976 | 11280 | 789 | 200 | 200 | | | | |
| 1977 | 12359 | 880 | 200 | 200 | | | | |
| 1978 | 13681 | 820 | 200 | 200 | | | | |
| 1979 | 9735 | 423 | 200 | 200 | | | | |
| 1980 | 8011 | 633 | 200 | 200 | | | | |
| 1981 | 5188 | 1407 | 200 | 200 | | | | |
| 1982 | 5140 | 663 | 200 | 200 | | | | |
| 1983 | 14108 | 692 | 200 | 200 | | | | |
| 1984 | 8756 | | 200 | 200 | | | | |
| 1985 | 1509 | | 200 | 200 | | | | |
| 1986 | 6536 | 2045 | 200 | 200 | | | | |
| 1987 | 8096 | 660 | 200 | 200 | | | | |
| 1988 | 4493 | 993 | 200 | 200 | | | | |
| 1989 | 3776 | 837 | 200 | 200 | | | | |
| 1990 | 731 | 220 | 200 | 200 | | | | |
| 1991 | 4363 | 504 | 200 | 200 | | | | |
| 1992 | | | | | | | | |
| 1993 | | 589 | | 6 | | 336 | | 25 |
| 1994 | | | | | | 671 | | 19 |
| 1995 | | | | | | | | |
| 1996 | | 533 | | 5 | | | | |
| 1997 | | 165 | | 2 | | 339 | | 7 |
| 1998 | 6031 | 2280 | 44 | 17 | 697 | 446 | 8 | 6 |
| 1999 | 9288 | 2744 | 84 | 18 | 339 | 848 | 3 | 8 |
| 2000 | 10691 | 750 | 96 | 6 | 634 | 434 | 7 | 4 |
| 2001 | 10647 | 2620 | 87 | 22 | 4376 | 1987 | 44 | 17 |
| 2002 | 7049 | 1140 | 63 | 11 | 3407 | 914 | 35 | 8 |
| 2003 | 6928 | 1291 | 60 | 18 | 2191 | 1302 | 22 | 15 |
| 2004 | 6559 | 481 | 59 | 4 | 2677 | 837 | 28 | 13 |
| 2005 | 8479 | 578 | 62 | 5 | 1579 | 495 | 13 | 6 |
| 2006 | 8432 | 1362 | 71 | 9 | 114 | 407 | 1 | 6 |
| 2007 | 646 | | 31 | | | | | |
| 2008 | 813 | 422 | 19 | 10 | 190 | 140 | 3 | 5 |
| 2009 | 742 | | 13 | | 487 | | 7 | |
| 2010 | 655 | 596 | 11 | 13 | 272 | | 4 | |
| 2011 | 379 | 103 | 11 | 5 | | | | |
| 2012 | 657 | | 16 | | | | | |
| 2013 | 811 | 115 | 20 | 5 | | 230 | | 3 |
| 2014 | 1373 | 166 | 25 | 4 | 145 | | 5 | |
| 2015 | 1265 | | 33 | | 620 | | 15 | |
| 2016 | 947 | | 10 | | 512 | | 6 | |
| 2017 | 587 | | 10 | | 128 | | 5 | |
| 2018 | 134 | | 2 | | | | | |
| 2019 | 1047 | | 22 | | 1301 | 305 | 31 | 16 |

**Table 4. Number of port retained lengths and number of trips by fleet used for length frequencies included in the base case assessment by fleet 1975-2019.**

| Year | Number of fish | | Number of trips | |
|---|---|---|---|---|
| | NSW | EBASS | NSW | EBASS |
| 1975 | 7343 | 289 | 200 | 29 |
| 1976 | 11280 | 789 | 200 | 79 |
| 1977 | 12359 | 56073 | 200 | 200 |
| 1978 | 13681 | 820 | 200 | 82 |
| 1979 | 9735 | 423 | 200 | 42 |
| 1980 | 8011 | 633 | 200 | 63 |
| 1981 | 5188 | 1407 | 200 | 141 |
| 1982 | 5140 | 663 | 200 | 66 |
| 1983 | 14108 | 692 | 200 | 69 |
| 1984 | 8756 | | 200 | |
| 1985 | 1509 | | 151 | |
| 1986 | 6536 | 2045 | 200 | 99 |
| 1987 | 8096 | 660 | 200 | 84 |
| 1988 | 4493 | 993 | 200 | 22 |
| 1989 | 3776 | 837 | 200 | 50 |
| 1990 | 731 | 220 | 73 | 6 |
| 1991 | 4363 | 504 | 200 | 5 |
| 1998 | 6031 | 2280 | 44 | 200 |
| 1999 | 9288 | 2744 | 84 | 2 |
| 2000 | 10691 | 750 | 96 | 17 |
| 2001 | 10647 | 2620 | 87 | 18 |
| 2002 | 7049 | 1140 | 63 | 6 |
| 2003 | 6928 | 1291 | 60 | 22 |
| 2004 | 6559 | 481 | 59 | 11 |
| 2005 | 8479 | 578 | 62 | 18 |
| 2006 | 8432 | 1362 | 71 | 4 |
| 2007 | 646 | | 31 | |
| 2008 | 813 | 422 | 19 | 9 |
| 2009 | 742 | | 13 | |
| 2010 | 655 | 596 | 11 | 10 |
| 2011 | 379 | 103 | 11 | 7 |
| 2012 | 657 | | 16 | |
| 2013 | 811 | 115 | 20 | 5 |
| 2014 | 1373 | 166 | 25 | 1 |
| 2015 | 1265 | | 33 | |
| 2016 | 947 | | 10 | |
| 2017 | 587 | | 10 | |
| 2018 | 134 | | 2 | |
| 2019 | 1047 | | 22 | |

**Table 5. Number of age-length otolith samples by fleet included in the base case assessment by fleet 1991-2019.**

| Year | NSW | EBASS | Total |
|---|---|---|---|
| 1991 | 241 | | 241 |
| 1992 | 608 | | 608 |
| 1993 | 888 | | 888 |
| 1994 | 700 | 98 | 798 |
| 1995 | 279 | | 279 |
| 1996 | 1074 | | 1074 |
| 1997 | 1076 | 47 | 1123 |
| 1998 | 935 | | 935 |
| 1999 | 1173 | | 1173 |
| 2000 | 745 | | 745 |
| 2001 | 1258 | | 1258 |
| 2002 | 672 | | 672 |
| 2003 | 658 | | 658 |
| 2004 | 684 | | 684 |
| 2005 | 582 | | 582 |
| 2006 | 263 | | 263 |
| 2007 | 128 | | 128 |
| 2008 | 393 | 12 | 405 |
| 2009 | 114 | 538 | 652 |
| 2010 | 177 | 537 | 714 |
| 2011 | 136 | 814 | 950 |
| 2012 | 324 | 355 | 679 |
| 2013 | 322 | 113 | 435 |
| 2014 | 214 | 295 | 509 |
| 2015 | 411 | 240 | 651 |
| 2016 | 87 | 24 | 111 |
| 2017 | 33 | 31 | 64 |
| 2018 | 124 | 144 | 268 |
| 2019 | 514 | 144 | 658 |

**Table 6. The standard deviation (SD) of age reading error.**

| Age | Expected Age | SD | Age | Expected Age | SD | Age | Expected Age | SD |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.5 | 0.244577 | 14 | 14.5 | 0.738154 | 28 | 28.5 | 1.205 |
| 1 | 1.5 | 0.244577 | 15 | 15.5 | 0.773625 | 29 | 29.5 | 1.236 |
| 2 | 2.5 | 0.284775 | 16 | 16.5 | 0.808757 | 30 | 30.5 | 1.26671 |
| 3 | 3.5 | 0.324588 | 17 | 17.5 | 0.843552 | 31 | 31.5 | 1.29712 |
| 4 | 4.5 | 0.364019 | 18 | 18.5 | 0.878015 | 32 | 32.5 | 1.32724 |
| 5 | 5.5 | 0.403073 | 19 | 19.5 | 0.912147 | 33 | 33.5 | 1.35707 |
| 6 | 6.5 | 0.441753 | 20 | 20.5 | 0.945953 | 34 | 34.5 | 1.38661 |
| 7 | 7.5 | 0.480063 | 21 | 21.5 | 0.979434 | 35 | 35.5 | 1.41587 |
| 8 | 8.5 | 0.518006 | 22 | 22.5 | 1.0126 | 36 | 36.5 | 1.44486 |
| 9 | 9.5 | 0.555585 | 23 | 23.5 | 1.04544 | 37 | 37.5 | 1.47356 |
| 10 | 10.5 | 0.592805 | 24 | 24.5 | 1.07797 | 38 | 38.5 | 1.50199 |
| 11 | 11.5 | 0.629668 | 25 | 25.5 | 1.11019 | 39 | 39.5 | 1.53015 |
| 12 | 12.5 | 0.666178 | 26 | 26.5 | 1.1421 | 40 | 40.5 | 1.55804 |
| 13 | 13.5 | 0.702339 | 27 | 27.5 | 1.1737 | | | |

### 2.2.7 Tuning method

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2018). Most of the indices (CPUE, surveys and composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error.

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

1. Set the standard error for the log of relative abundance indices (CPUE) to the standard 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 allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

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

2. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by SS-V3.30 at each step.

For the age and length composition data:

3. Multiply the stage-1 (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 2 - 4, until all are converged and stable (with proposed changes < 1 – 2%).

This procedure constitutes current best practice for tuning assessments.

## 2.3 Calculating the RBC

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. In 2009, AFMA directed that the 20:35:48 ($B_{lim}$: $B_{MSY}$: $F_{targ}$) form of the rule is used up to where fishing mortality reaches $F_{48}$, the default economic target for $B_{MEY}$. Once this point is reached, the target fishing mortality is set at $F_{48}$.

## 2.4 Sensitivity tests and alternative models

### 2.4.1 Standard sensitivities

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

1. $M$ = 0.06 $yr^{-1}$.
2. $M$ = 0.10 $yr^{-1}$.
3. Fix steepness ($h$) at 0.85.
4. Fix steepness ($h$) at 0.65.
5. Estimate steepness ($h$).
6. $\sigma_R$ set to 0.8.
7. $\sigma_R$ set to 0.6.
8. Double the weighting on the length composition data.
9. Halve the weighting on the length composition data.
10. Double the weighting on the age-at-length data.
11. Halve the weighting on the age-at-length data.
12. Double the weighting on the survey (CPUE) data.
13. Halve the weighting on the survey (CPUE) data.

The results of the sensitivity tests are summarized by the following quantities:

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 depletion level at the start of 2021.
4. $RBC_{2021}$: the recommended biological catch (RBC) for 2021.
5. $RBC_{longterm}$: the longterm RBC.

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

### 2.4.2 Additional sensitivities

As requested at the first RAG meeting in October 2020, an additional sensitivity looking at the effects of adding an extra time block at the end of the time series, between 2013 and 2019 was conducted. It was hypothesised that allowing retention to differ during this time, which coincided with the 100t bycatch TAC implementation, would improve fits to the end of the catch rate and discard series.

# 3 Results

## 3.1 The base case assessment model

### 3.1.1 Parameter estimates

Figure 5 shows the estimated growth curve for female and male Redfish. Selectivity is assumed to be logistic and not differ between the two regions, NSW and EBASS. 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 selectivity curve estimated by the model is displayed in Figure 6. Separate retention functions were estimated for each region to allow for different discarding practices. The two estimated retention functions are displayed in Figure 7.

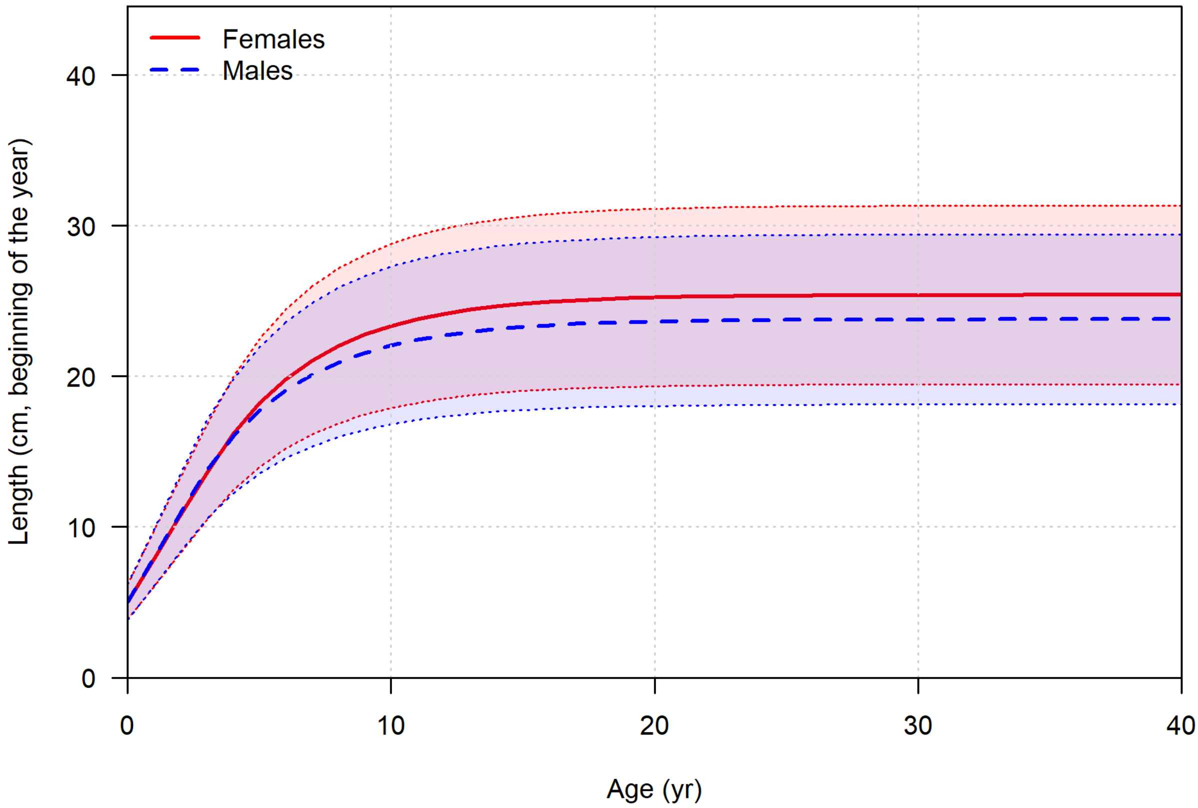



**Figure 5. The model estimated growth curves for the base case Redfish assessment, with 95% confidence intervals.**

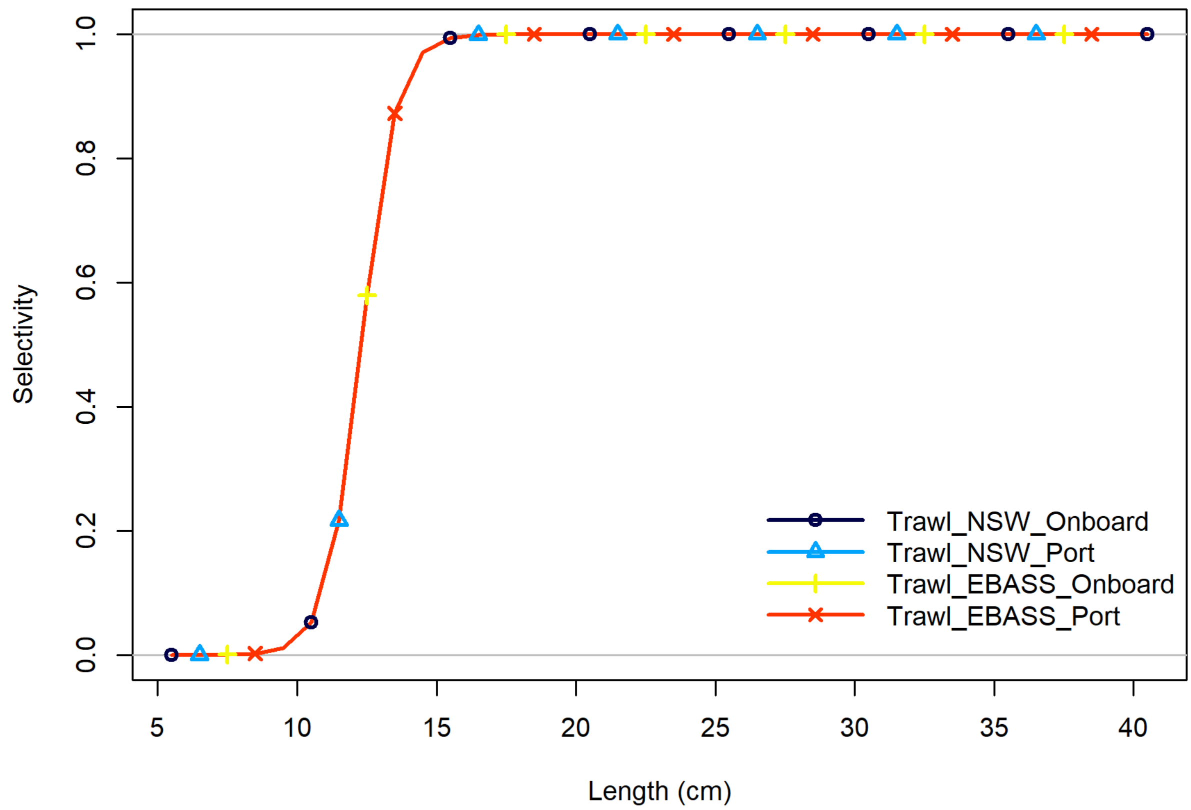



Figure 6. Estimated selectivity curves for Redfish.

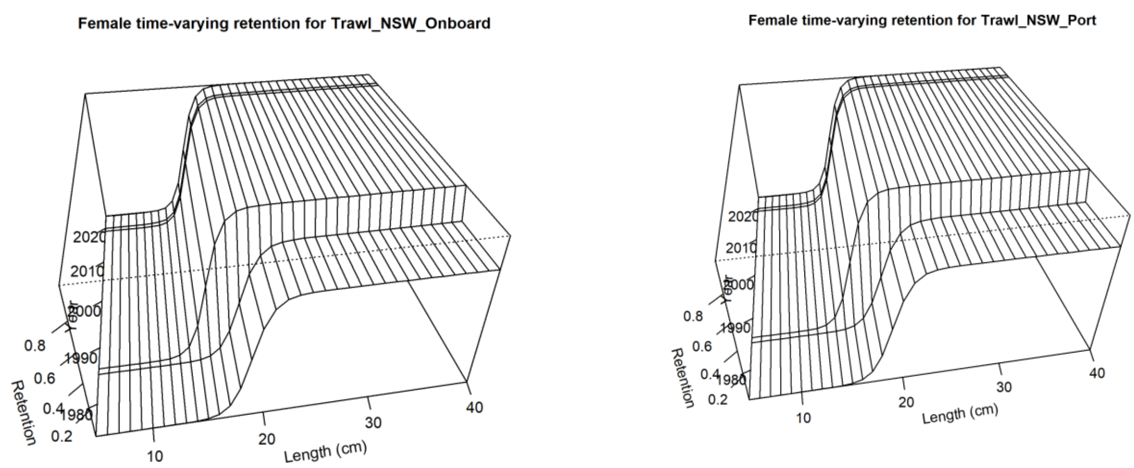



Figure 7. The base case estimated retention functions for each region in the Redfish base case model.

### 3.1.2 Fits to the data

The fits to standardised catch rates are reasonable, although the model tends to overestimate the biomass at the end of the time series in NSW, although estimates are still within the confidence intervals (Figure 8).

The base-case model fits most of the time aggregated retained length-frequency distributions well (Figure 10). Fits to the Trawl_NSW_Onboard data are poor, however, these data contain a mix of both retained and discarded fish from two years of data, with small adjusted effective samples sizes compared to the other length data (Figure 10). The annual length and age composition fits are shown in Appendix A.

The age compositions were not fitted to directly, as conditional 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 (Appendix A). Note that there are separate implied fits to age for both port and onboard data. There is only one set of age data, but this needs to be scaled up to length data (using an age-length key) to get implied fits to age. This scaling up to length data can be done using either the onboard length data or the port length data, so there are two separate sets of implied age data.

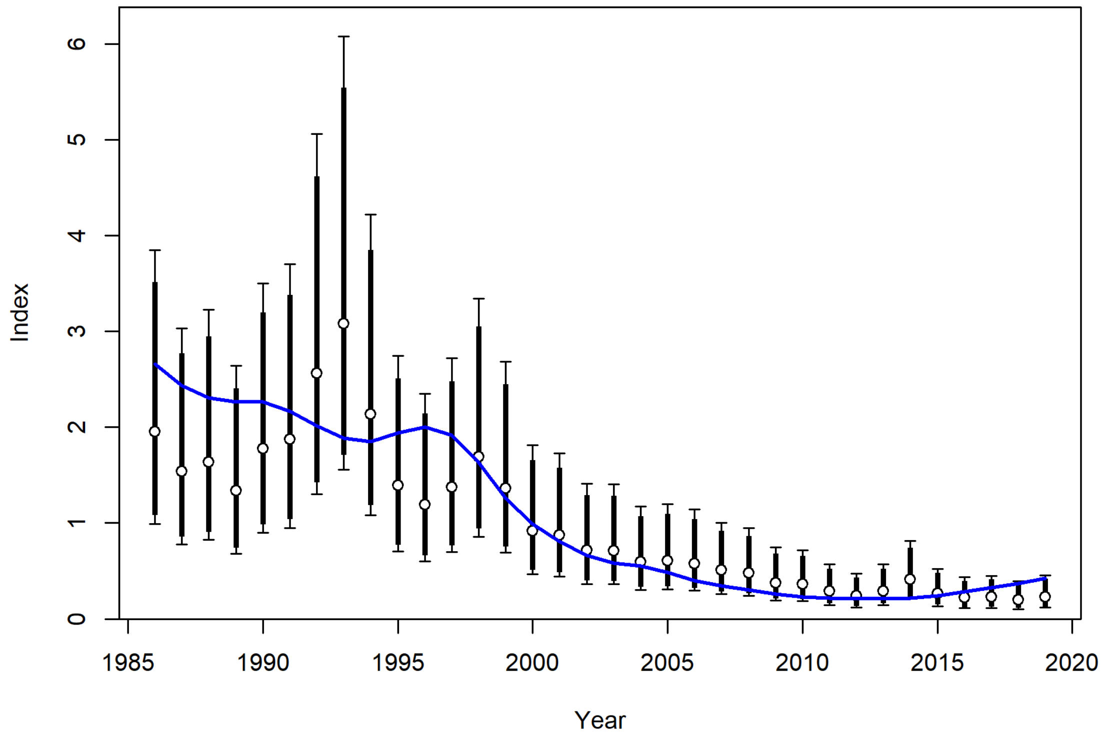



**Figure 8. Fits to NSW CPUE.**

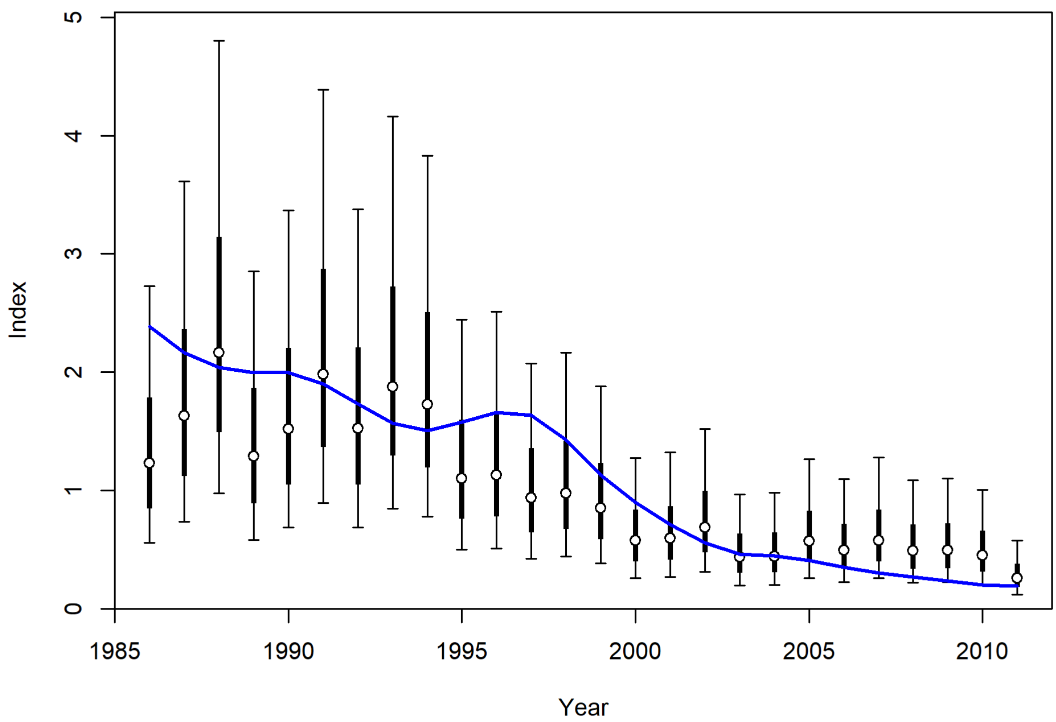



Figure 9. Fits to EBASS CPUE.

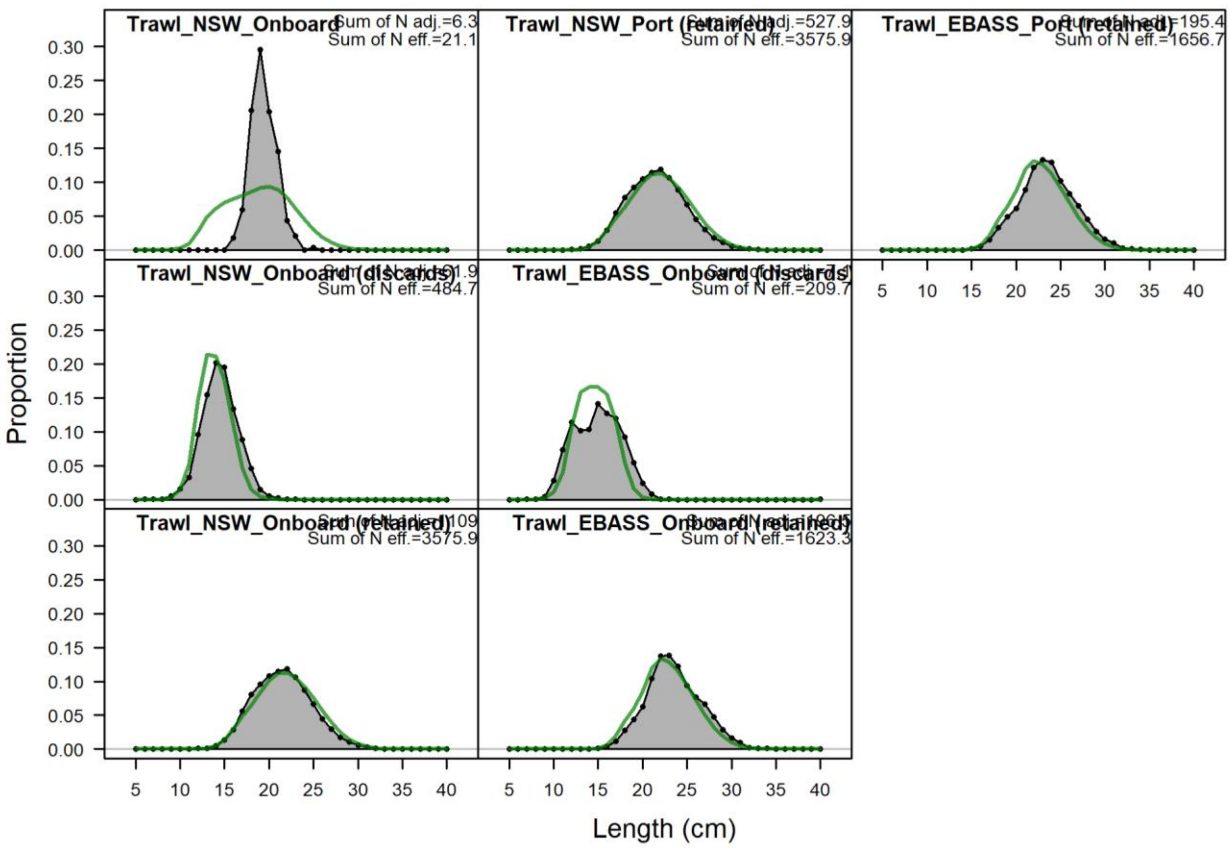



Figure 10. Aggregated fits (all years) to the length compositions for Redfish by fleet.

### 3.1.3 Assessment outcomes

This assessment estimates that the projected 2021 spawning stock biomass will be 3.81% of unfished stock biomass (projected assuming 2019 catches in 2020; Figure 11), compared to 7.72% at the start of 2018 from the 2017 assessment (Tuck et al., 2017). While changing the structure of the model had little effect on the estimated stock size, changing the natural morality rate (*M*) from a fixed value of 0.1 year$^{-1}$ to an estimated value within the model (0.075 year$^{-1}$) resulted in a downward revision of stock size.

The base case assessment estimated the unexploited female spawning biomass, $SSB_0$, to be 19,589t, while $SSB_{1974}$ at the start of the model timeseries is 15,986t (Figure 12). This decreases to 747t by 2021 (Figure 12).

Recruitments show a fluctuating pattern, with a recent period of poor recruitment from 2008 to 2011. However, the 2012 and 2013 estimated recruitments are closer to average (Figure 13, Figure 14).

The estimated stock recruitment curve demonstrated the relationship between the size of the population and the number of recruits produced in a year. The relationship shows that at the start of the time series, between 1975 and 1980, the spawning biomass was large and many recruits were produced (Figure 15). This was followed by a period of reduced spawning biomass but still high recruitment, between 1990 and 2000 (Figure 15). Since 2000, both spawning biomass and recruitment have been low (Figure 15).

The variance associated with estimation of recruitment deviations is shown in Figure 16. Between 1970 and 1990 there is a gradual decline in variance as more data is available to the model to inform estimation (Figure 16). The variance between 1990 and 2015 at the end of the recruitment deviation time series is relatively stable, suggesting that the model has sufficient information to inform the estimation of these deviations (Figure 16).

Figure 17 shows a phase plot for the base case analysis. 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. The assessment starts in the bottom right corner, when there was low fishing mortality and high biomass, to the present day, where fishing pressure immediately increased to above the target level, resulting in a decline in biomass moving to the top left corner of the plot (Figure 17). Fishing pressure has since declined below the target fishing mortality in the last 3 years (Figure 17).

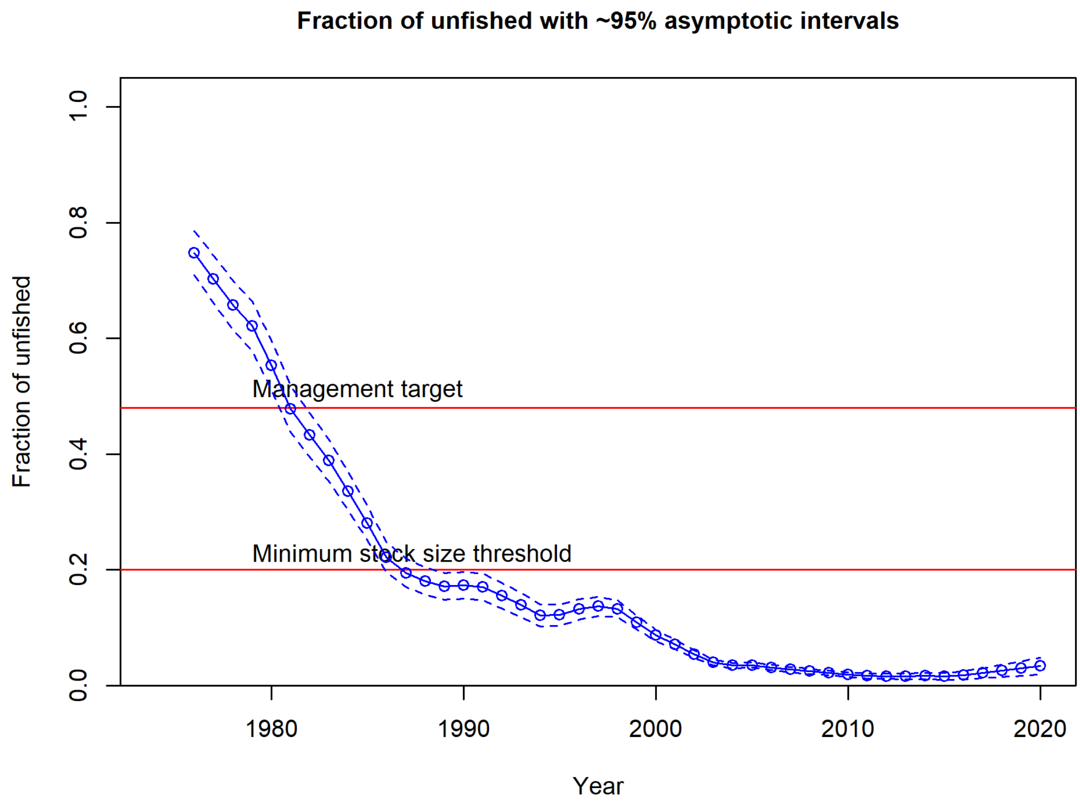



**Figure 11. The estimated time-series of relative spawning biomass 2020 base case assessment for Redfish.**

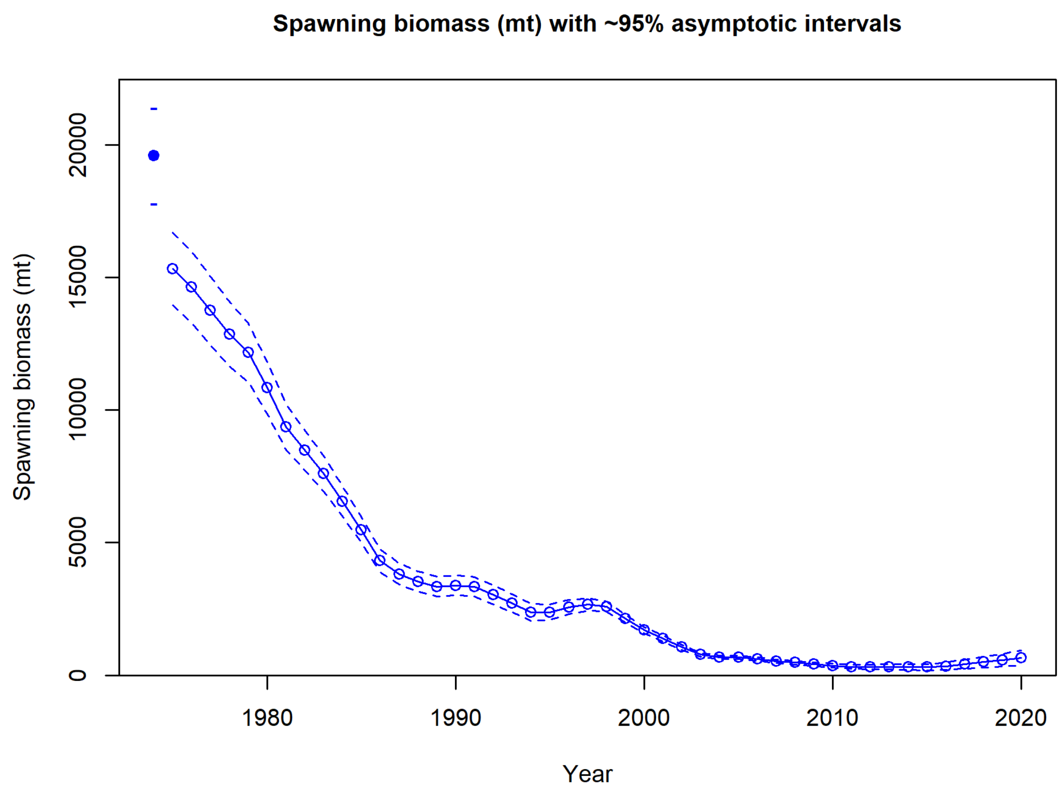



**Figure 12. The estimated time-series of absolute spawning biomass for the 2020 base case assessment for Redfish.**

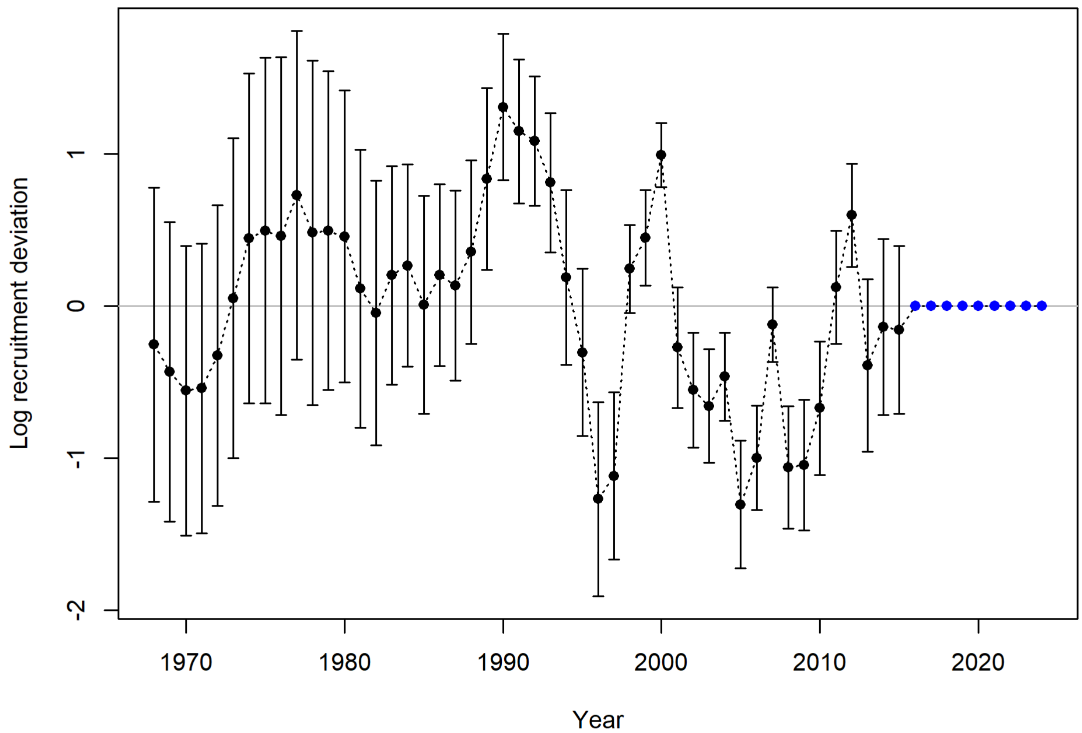



**Figure 13. Recruitment deviations with confidence intervals for Redfish.**

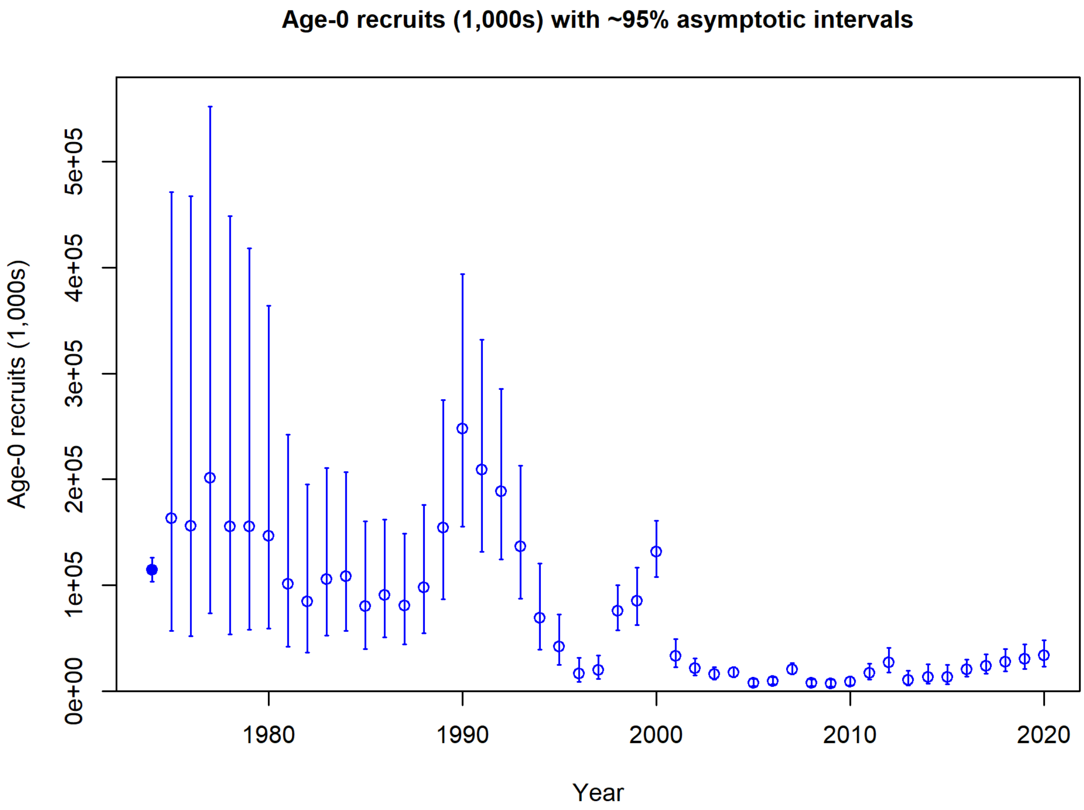



**Figure 14. Recruitment estimates with confidence intervals for Redfish.**

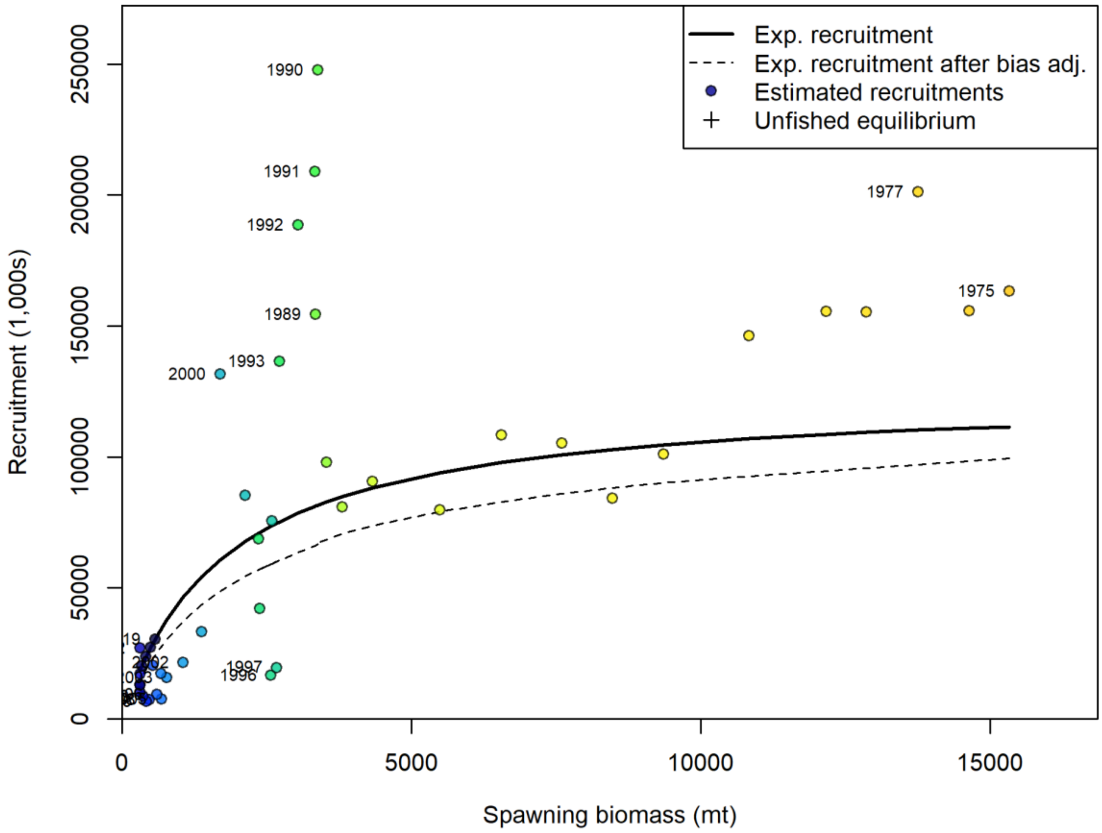



**Figure 15. Stock recruitment curve for Redfish.**

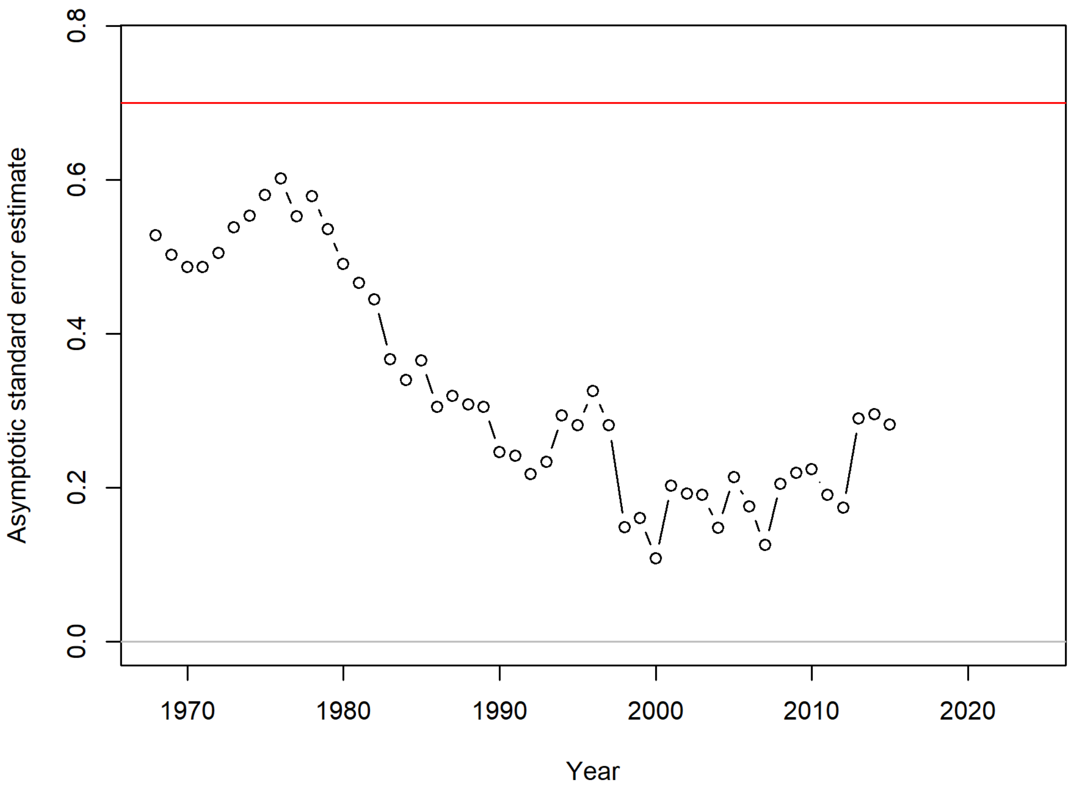



**Figure 16. Recruitment deviation variance check for Redfish.**

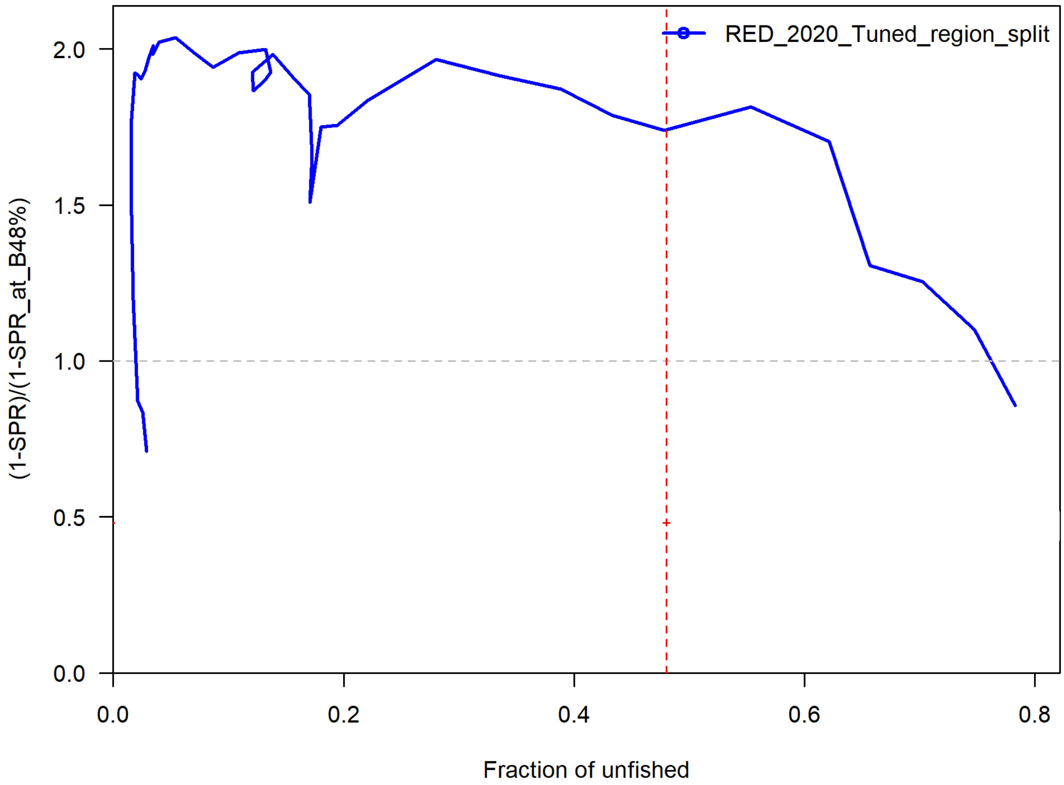



**Figure 17. Phase plot of biomass vs SPR ratio, the grey line represent the target fishing mortality, while the red line represents the target spawning biomass.**

## 3.2 Likelihood profiles

Likelihood profiles are a standard component of the toolbox of applied statisticians (Punt, 2018) and are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments “fix” key parameters such as natural mortality and steepness 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. If the parameter is within the range of the 95% confidence interval of the total likelihood profile, this provides no support from the data to change the fixed value. If the fixed value is outside the 95% confidence interval, and there is evidence that the data holds information about this parameter, 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 should 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 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 for key parameters of interest (such as natural mortality ($M$), steepness ($h$) and unfished spawning biomass ($SSB_{1975}$)) were presented in Bessell-Browne and Tuck (2020) for the single region, two selectivity base case. The assessment has now moved to a two-region model and updated likelihood profiles are presented here.

The likelihood profile for *M* suggests that this parameter could range from 0.066 and 0.083 year$^{-1}$ and that there is information in the data to support estimating this parameter (Figure 18). Some data informing this parameter within the model is conflicting, with age data suggesting higher values of *M*, while length data suggests lower values (Figure 18). There is limited information in the discard, index and recruitment data to inform estimation of *M* (Figure 18).

The likelihood profile *h* suggests there is little information in the model that can inform estimation of this parameter (fixed at 0.75 in the model, Figure 19). There is conflict in the data inputs, with this driven by discard and length data, which suggest a lower value of *h* is preferable, while recruitment and index data suggest higher values are more appropriate (Figure 19).

The depletion likelihood profile suggests that the model estimates depletion in 2019 with high certainty (Figure 20). The model suggests that 2019 depletion ranges between 2% and 4.75% of unfished levels (Figure 20).

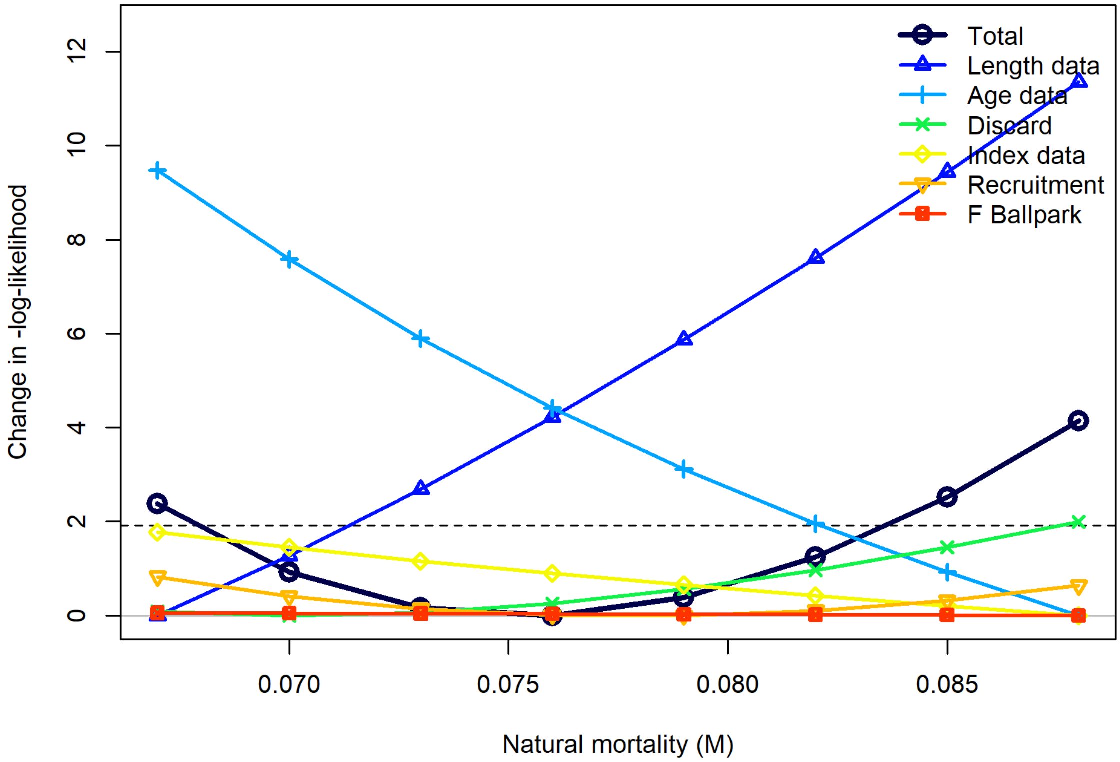



**Figure 18. The likelihood profile for natural morality (*M*). M is estimated in the base case at 0.075 year$^{-1}$.**

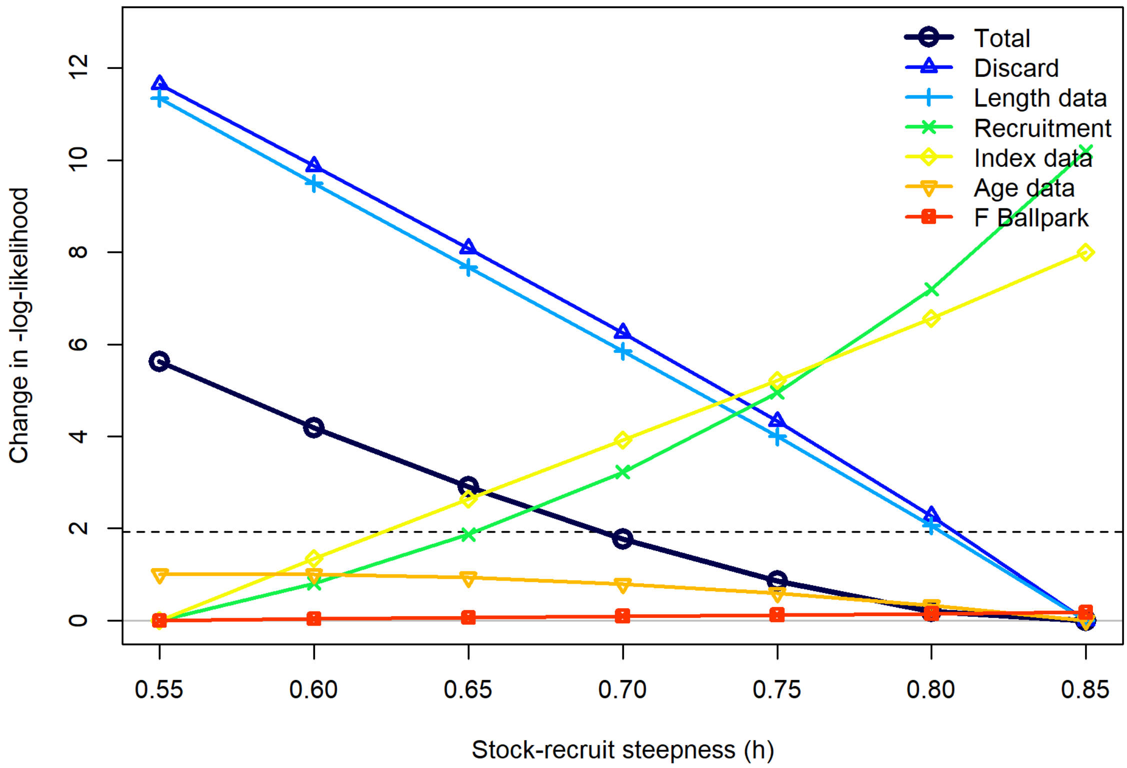



**Figure 19. The likelihood profile for stock-recruitment steepness (*h*), *h* is fixed in the base case model at 0.75.**

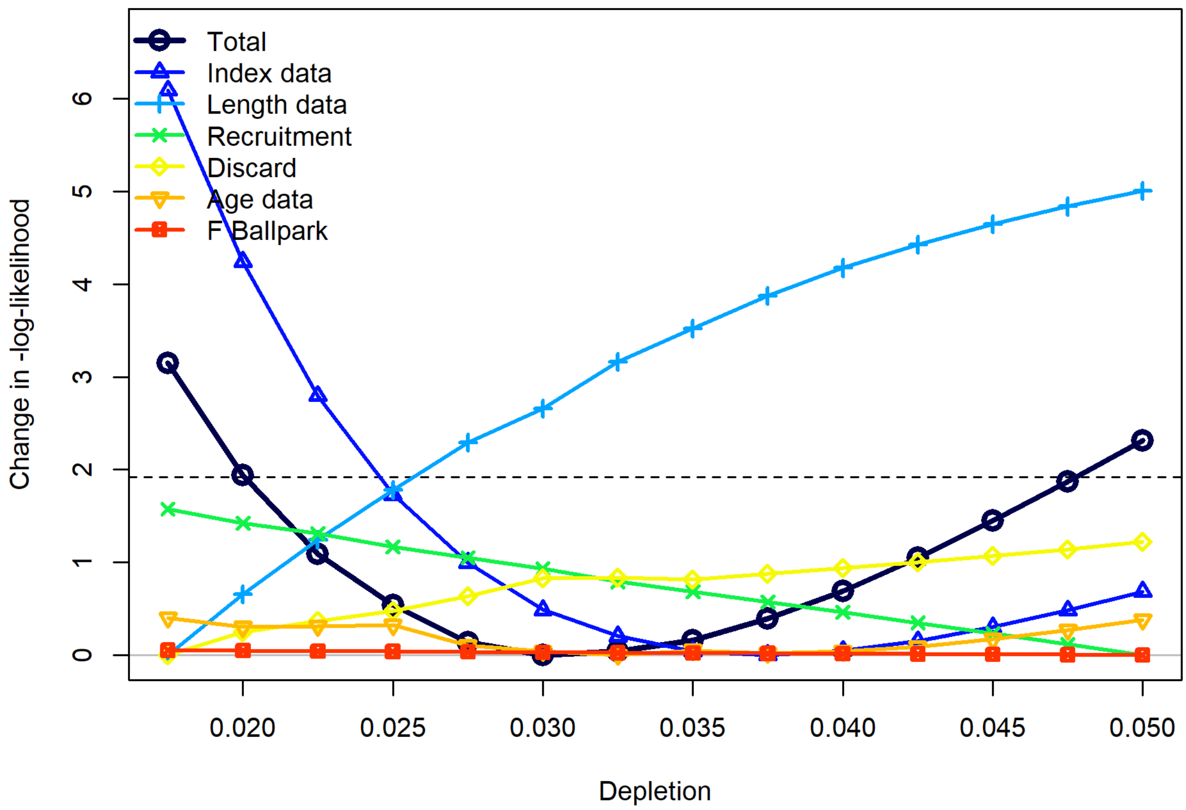



**Figure 20. The likelihood profile for Depletion in 2019. In the model, 2019 Depletion is estimated to be 0.0296 or 2.96% of unfished levels.**

## 3.3 Standard and low recruitment projections

Estimates of recruitment strength for Redfish show considerably lower values than average since the early 2000s (Figure 13), with this potentially a consequence of directional environmental change. The base case model assumes that recruitment values are taken from the stock recruitment curve for historical years that are not estimated and for future projections (in our case from 2016 onwards). If there has been an environmental driven change in productivity, this may be an overly optimistic recruitment scenario. The following scenario projects recruitments from 2016 onwards with the average recruitment deviations taken from the 10-year period 2006 to 2015 (average = -0.39). Note this is considerably higher than the 10-year average recruitment deviation from the 2017 Redfish assessment, being -1.1, Tuck et al., 2018), leading to larger projected recruitments and more rapid recovery than the 'low recruitment' projections shown in 2017. Constant annual catches are then projected with low recruitments to explore future potential trajectories of biomass.

As the low recruitment scenario markedly reduces stock productivity, it takes longer to recover to the limit reference point for annual catches of 50t or more (2020 retained catch is estimated to be 34t) than if average recruitment is assumed (Figure 21). Under the standard harvest control rule and recruitment model (that uses recruitments from the stock-recruitment curve), the spawning biomass is estimated to pass 20% of initial biomass levels by approximately 2032 (HCR; Figure 21, Table 7). With a fixed annual catch of 100t from 2021 and the standard recruitment model, the spawning biomass is estimated to pass 20% of unfished biomass levels by approximately 2035 (C100 AveR, Figure 21). The three-year delay in passing 20% of initial biomass is because the standard HCR assumes no retained catch when the biomass is below the limit reference point, compared to a fixed 100t for all future years for the C100 AveR scenario (Figure 21). Table 7 provides annual depletion, retained and estimated discards for the standard harvest control rule (HCR), the 100t fixed catch with low recruitment (C100 of Figure 21), and the 100t fixed catch scenario with average recruitment (C100 AveR), with catches and discards summed across both the NSW and EBASS fleets.

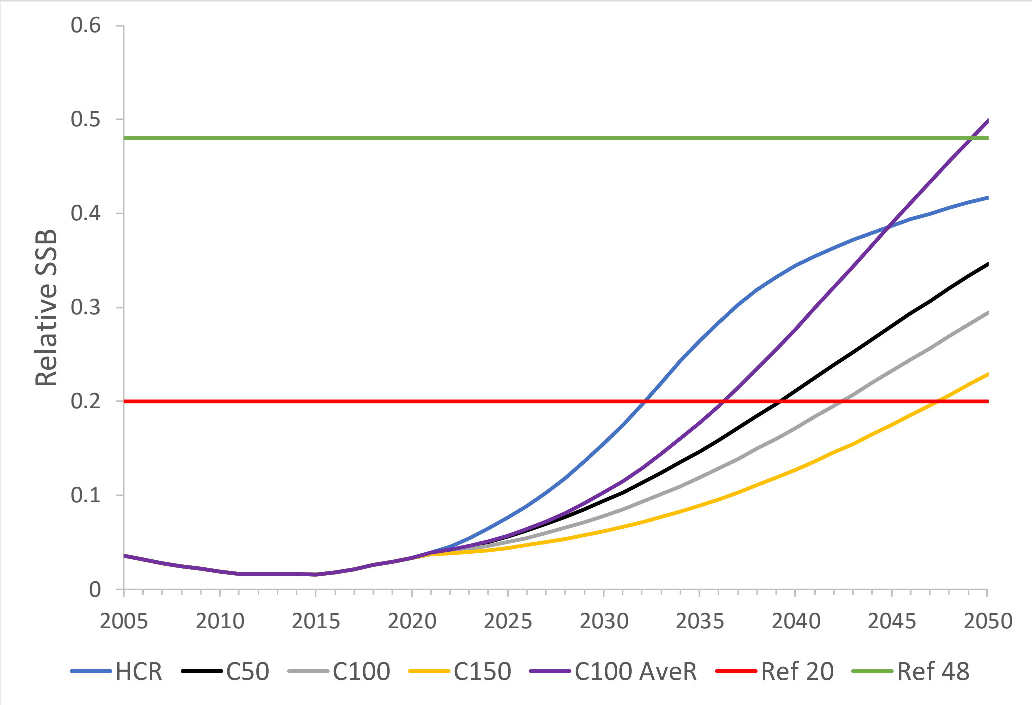



**Figure 21. Relative spawning biomass time-series for standard SESSF harvest control rule (blue HCR), and four alternative constant catch scenarios: three with low recruitment (catches of 50t, 100t, 150t; black, grey and orange respectively) and one with standard recruitment drawn from the S-R curve with 100t annual catch from 2018 onwards (purple C100 aveR). The red and green lines are the limit (Ref 20) and target (Ref 48) biomass depletion levels.**

**Table 7. Depletion levels, retained catch (t) and estimated discarded catch (t) corresponding to the projection scenarios of Figure 21.**

| | HCR | | | C100 Low Recruitment | | | C100 Ave Recruitment | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Depl | Ret | Disc | Depl | Ret | Disc | Depl | Ret | Disc |
| 2020 | 0.03 | 34.1 | 7.4 | 0.03 | 34.1 | 5.7 | 0.03 | 34.1 | 7.4 |
| 2021 | 0.04 | 0.0 | 0.0 | 0.04 | 100.0 | 16.8 | 0.04 | 100.0 | 22.0 |
| 2022 | 0.05 | 0.0 | 0.0 | 0.04 | 100.0 | 17.2 | 0.04 | 100.0 | 21.8 |
| 2023 | 0.05 | 0.0 | 0.0 | 0.04 | 100.0 | 17.4 | 0.05 | 100.0 | 21.4 |
| 2024 | 0.06 | 0.0 | 0.0 | 0.05 | 100.0 | 17.4 | 0.06 | 100.0 | 20.9 |
| 2025 | 0.08 | 0.0 | 0.0 | 0.05 | 100.0 | 17.1 | 0.06 | 100.0 | 20.2 |
| 2026 | 0.09 | 0.0 | 0.0 | 0.05 | 100.0 | 16.7 | 0.07 | 100.0 | 19.5 |
| 2027 | 0.10 | 0.0 | 0.0 | 0.06 | 100.0 | 16.2 | 0.08 | 100.0 | 18.8 |
| 2028 | 0.12 | 0.0 | 0.0 | 0.07 | 100.0 | 15.8 | 0.09 | 100.0 | 18.1 |
| 2029 | 0.14 | 0.0 | 0.0 | 0.07 | 100.0 | 15.4 | 0.11 | 100.0 | 17.5 |
| 2030 | 0.15 | 0.0 | 0.0 | 0.08 | 100.0 | 15.0 | 0.12 | 100.0 | 16.8 |
| 2031 | 0.17 | 0.0 | 0.0 | 0.09 | 100.0 | 14.7 | 0.14 | 100.0 | 16.2 |
| 2032 | 0.20 | 0.0 | 0.0 | 0.09 | 100.0 | 14.3 | 0.15 | 100.0 | 15.5 |
| 2033 | 0.22 | 53.1 | 7.1 | 0.10 | 100.0 | 13.9 | 0.17 | 100.0 | 14.9 |
| 2034 | 0.24 | 125.1 | 16.0 | 0.11 | 100.0 | 13.6 | 0.19 | 100.0 | 14.3 |
| 2035 | 0.26 | 203.9 | 25.1 | 0.12 | 100.0 | 13.2 | 0.21 | 100.0 | 13.7 |

## 3.4 Sensitivities to the base case model

Standard sensitivities to alternative natural mortality values (*M*=0.06, 0.10), steepness (*h*=0.65, 0.85, and *h* estimated), and variation in data weighting were considered (Table 8 and Table 9). The base-case model and sensitivities all have stock status less than the limit reference point of 20% of unfished spawning biomass, and generally vary between 2% and 4% of unfished spawning stock biomass (Table 8).

**Table 8. Summary of sensitivity results for the base-case model.**

| Case | | $SSB_0$ | $SSB_{2019}$ | $SSB_{2019}$ / $SSB_0$ |
|---|---|---|---|---|
| 0 | Base case 20:35:48 est M (0.075) | 19415 | 653 | 0.03 |
| 1 | *M*=0.06 | 22324 | 524 | 0.02 |
| 2 | *M*=0.10 | 15468 | 937 | 0.06 |
| 3 | *Steepness, h*=0.65 | 19415 | 653 | 0.03 |
| 4 | Steepness, *h* =0.85 | 19415 | 653 | 0.03 |
| 5 | Estimate steepness (0.75), M = 0.075 | 18975 | 682 | 0.04 |
| 6 | Double length weights | 20400 | 585 | 0.03 |
| 7 | Halve length weights | 18118 | 708 | 0.04 |
| 8 | Double age weights | 17698 | 594 | 0.03 |
| 9 | Halve age weights | 20871 | 707 | 0.03 |
| 10 | Double CPUE weights | 19011 | 691 | 0.04 |
| 11 | Halve CPUE weights | 19574 | 516 | 0.03 |

**Table 9. Summary of likelihood components for the base-case model structure and sensitivity tests. Sensitivities from the base case are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.**

| Case | Model | TOTAL | CPUE | Discard | Length comp | Age comp | Recruit |
|---|---|---|---|---|---|---|---|
| 0 | Base case est M (0.075) | 2195.49 | -29.46 | 268.92 | 328.71 | 1618.6 | 7.93 |
| 1 | *M*=0.06 | 8.92 | 1.74 | 3.41 | -6.25 | 10.25 | 2.43 |
| 2 | *M*=0.10 | 13.11 | -1.79 | 3.41 | 15.8 | -7.71 | 2.76 |
| 3 | *Steepness, h*=0.65 | 0 | 0 | -0.71 | 0 | 0 | 0 |
| 4 | Steepness, *h* =0.85 | 0 | 0 | -0.71 | 0 | 0 | 0 |
| 5 | Est steepness (0.75) | 0.37 | -0.41 | -0.18 | 1.73 | -1.17 | -0.31 |
| 6 | Double length weights | 194.6 | 3.13 | 25.02 | 156.53 | 8.74 | 0.38 |
| 7 | Halve length weights | -109.67 | -2.15 | -19.11 | -85.19 | -4.89 | 1.01 |
| 8 | Double age weights | 1596.68 | 0.92 | 35.97 | 10.13 | 1546.81 | 2.21 |
| 9 | Halve age weights | -822.06 | -0.77 | -36.99 | -9.3 | -777.54 | -17.6 |
| 10 | Double CPUE weights | -32 | -39.19 | -1 | 4.67 | 1.54 | 1.27 |
| 11 | Halve CPUE weights | 13.82 | 16.9 | 0.02 | -2.7 | -0.95 | -0.17 |

### 3.4.1 Extra sensitivities: 2013-2019 retention time block

During the October 2020 RAG meeting a sensitivity investigating the impacts of adding an extra retention time block between 2013 and 2019 was requested. Adding a third retention block aimed to allow improved model fits to the end of the catch rate and discard time series. It was anticipated that discard practices may have changed during this period due to the implementation of the bycatch TAC to facilitate rebuilding of the stock.

There was very little difference between estimates of both relative and absolute spawning stock biomass for the base case and the model with the extra time block (Figure 22, Figure 23). The extra time block sensitivity estimates that the population size in both absolute and relative terms is slightly higher than the base case model, with 2021 relative biomass estimated to be 3.81%, while the model with the extra time block estimates it to be 5.75% (Figure 22, Figure 23).

Differences between the fits to standardised CPUE are minimal between the two models (Figure 24). The sensitivity model with an extra time block estimates lower CPUE between 1985 and 1997 compared to the base case (Figure 24). At the end of the time series, in 2018 and 2019, the sensitivity model estimates CPUE slightly lower than the base case model, although still over-estimates values compared to those input to the model (Figure 24).

Differences between the estimated recruitment deviations were evident between the models and this is particularly evident at the end of the time series (Figure 25). Between 2010 and 2015 the sensitivity model with the extra time block has revised the recruitment deviations downward (Figure 25). This has reduced the only above average recruitment deviation to be revised down to average levels, with the remainder all below average (Figure 25).

Fits to discard data were considerably improved between 2013 and 2019 for the extra time block sensitivity. In contrast, the improvements in fits to the discards in EBASS were not as pronounced. Fits to the discarded length structures were poor compared to the base case.

Model diagnostics for the extra time block sensitivity are presented in Appendix B.

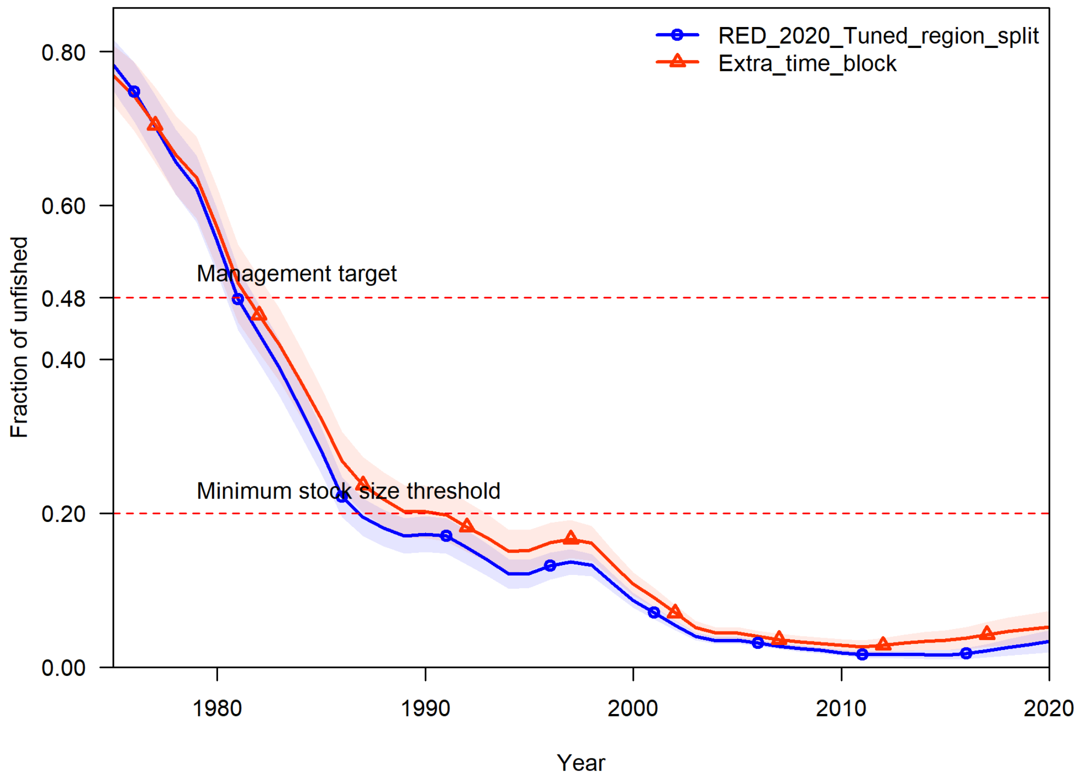



**Figure 22. Comparison of the estimated time-series of relative spawning biomass between the base case (RED_2020_Tuned_region_split) and the sensitivity with an extra time block between 2013 and 2019 (Extra_time_block).**

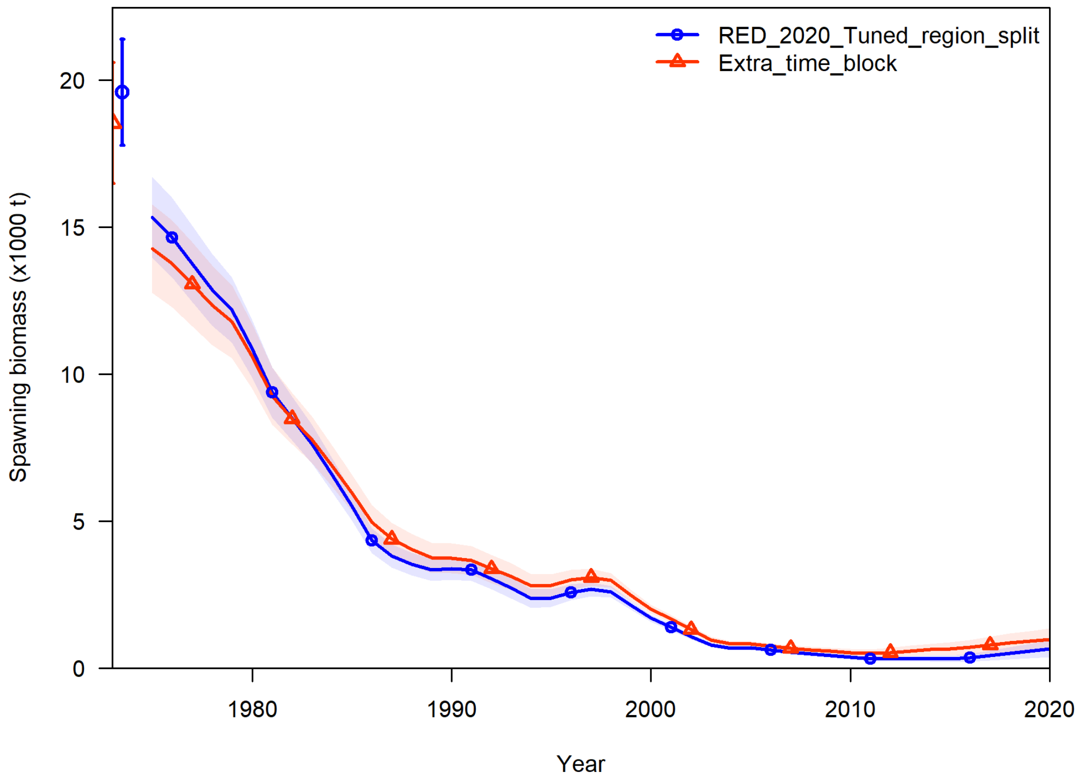



**Figure 23. Comparison of the estimated time-series of absolute spawning biomass between the base case (RED_2020_Tuned_region_split) and the sensitivity with an extra time block between 2013 and 2019 (Extra_time_block).**

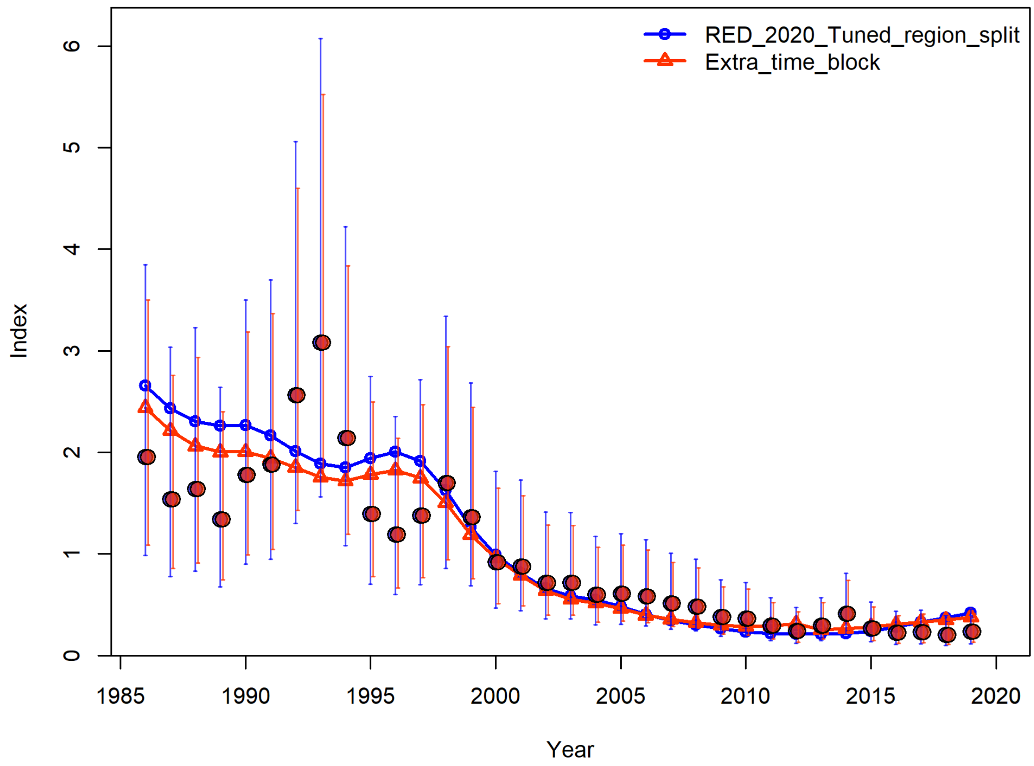



**Figure 24. Comparison of the fits to standardised catch rates between the base case (RED_2020_Tuned_region_split) and the sensitivity with an extra time block between 2013 and 2019 (Extra_time_block).**

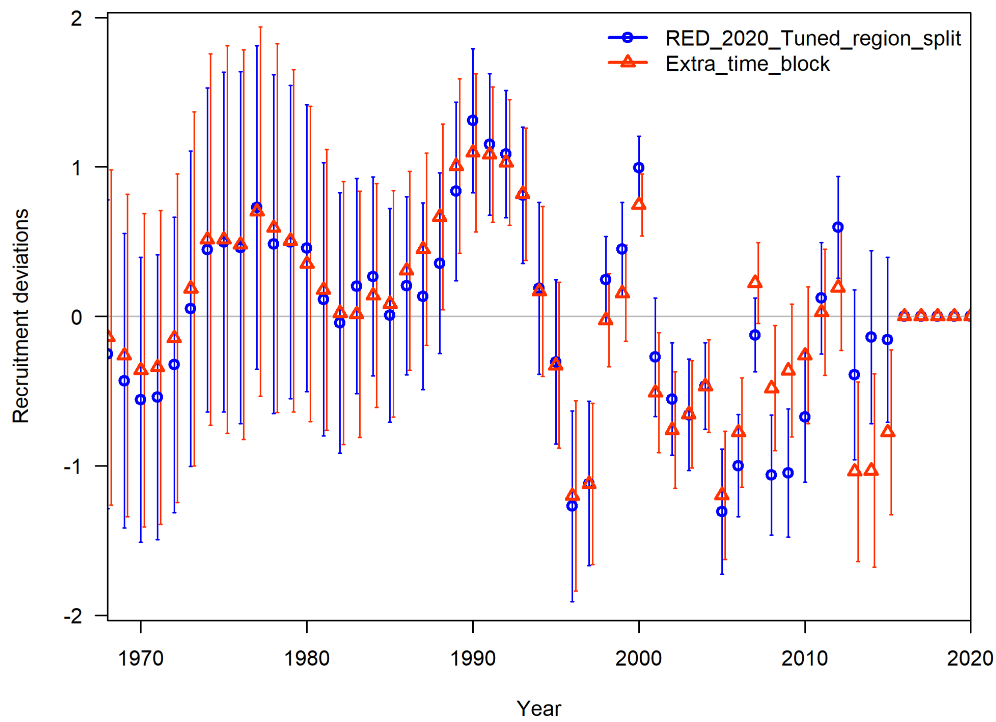



**Figure 25. Comparison of the estimated recruitment deviations between the base case (RED_2020_Tuned_region_split) and the sensitivity with an extra time block between 2013 and 2019 (Extra_time_block).**

# 4 Conclusions and future directions

The suggestions from the previous Redfish assessment have been incorporated here with the separation of fleets into two regions, NSW and EBASS, to account for differences in port length structures between the two areas (Tuck et al., 2017). This alteration has allowed one selectivity pattern to be used for both onboard and port data and across both regions, with separate retention functions between regions. Although this change did not result in noticeable changes to stock status estimates, it did improve fits to the data, particularly CPUE, and has resolved patterns in the retrospective analysis from the previous model structure (Bessell-Browne and Tuck, 2020).

The assessment suggests that the spawning stock biomass of Redfish is well below the limit reference point and that it has been below this limit since the late 1980s. This extended period of depletion raises concerns regarding whether standardised CPUE is still indexing abundance of the population. This is likely exacerbated by very low total harvest observed in recent years. Without a reliable, informative index of abundance, it is difficult to confidently determine or project recovery of the population. This problem is not only faced by this species, but also others in the SESSF and globally. Future assessments should investigate whether the CPUE used in the assessment is indexing abundance, and if other methodologies exist that can more appropriately account for the possible disconnection between CPUE and abundance, therefore allowing more accurate estimates of biomass.

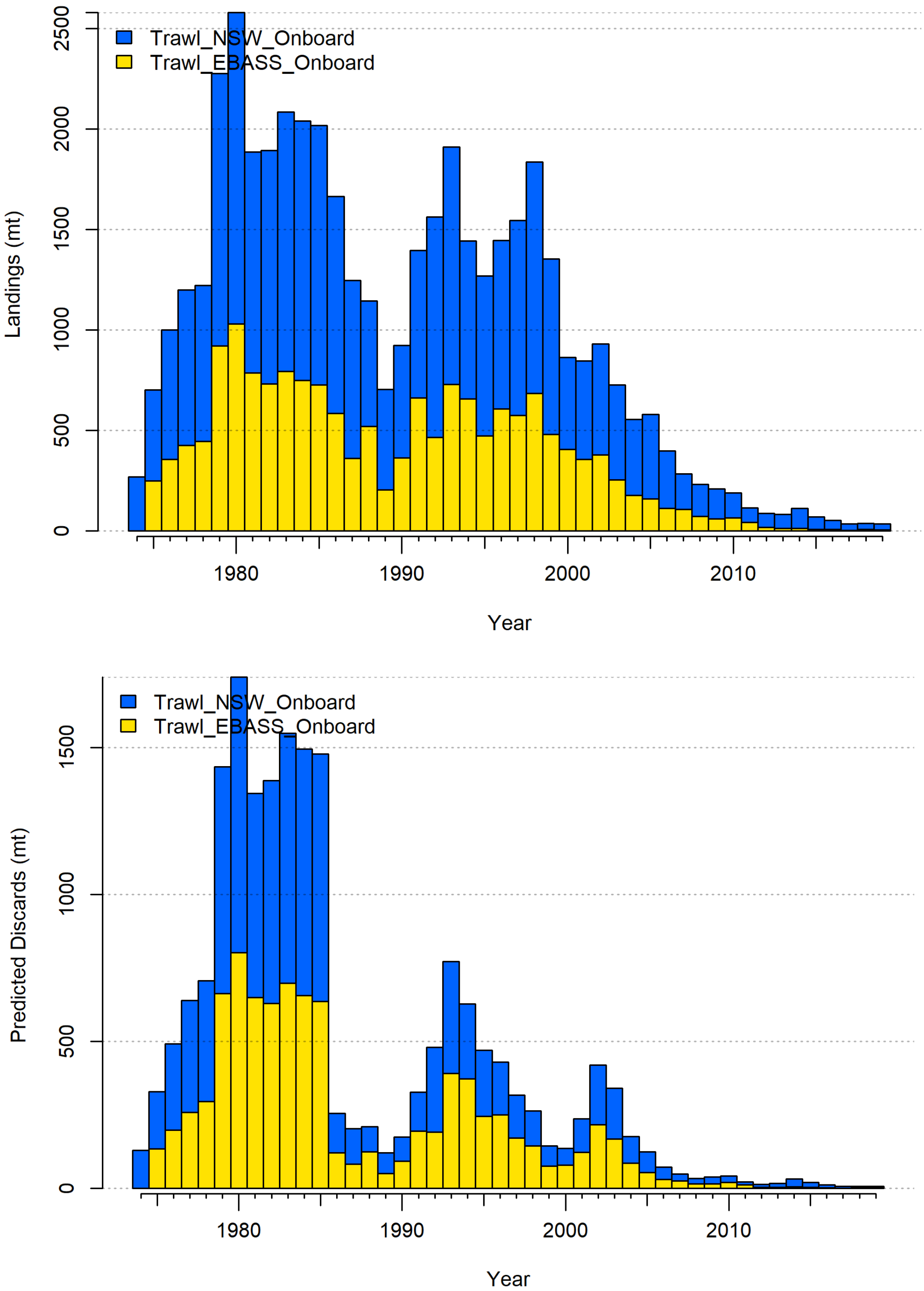
Based on the likelihood profile based criteria for estimating a parameter within an assessment model outlined in Punt (2018), natural mortality now is estimated in the base case. Estimating natural mortality in the model has resulted in lower biomass estimates than previous assessments, where this parameter was fixed at 0.1 year$^{-1}$. The change in this parameter has resulted in a decrease in the estimated population size, with relative spawning biomass as low as 1.60% in 2015. Whether these low estimates are realistic is yet to be determined. Further investigations into the estimated value of natural mortality at 0.075 year$^{-1}$ is warranted. Regardless of the value of natural mortality used in this assessment, the population size is still estimated to be well below the limit reference point.

Investigation into the historical catch series used in this assessment has revealed that catches in the time series are lower in some years than the recorded NSW catches, suggesting that total catches may have been higher (pers. comm. Geoffrey Liggins, NSW). This discrepancy should be investigated before the next assessment to ensure that the most accurate time series is used in future assessments.

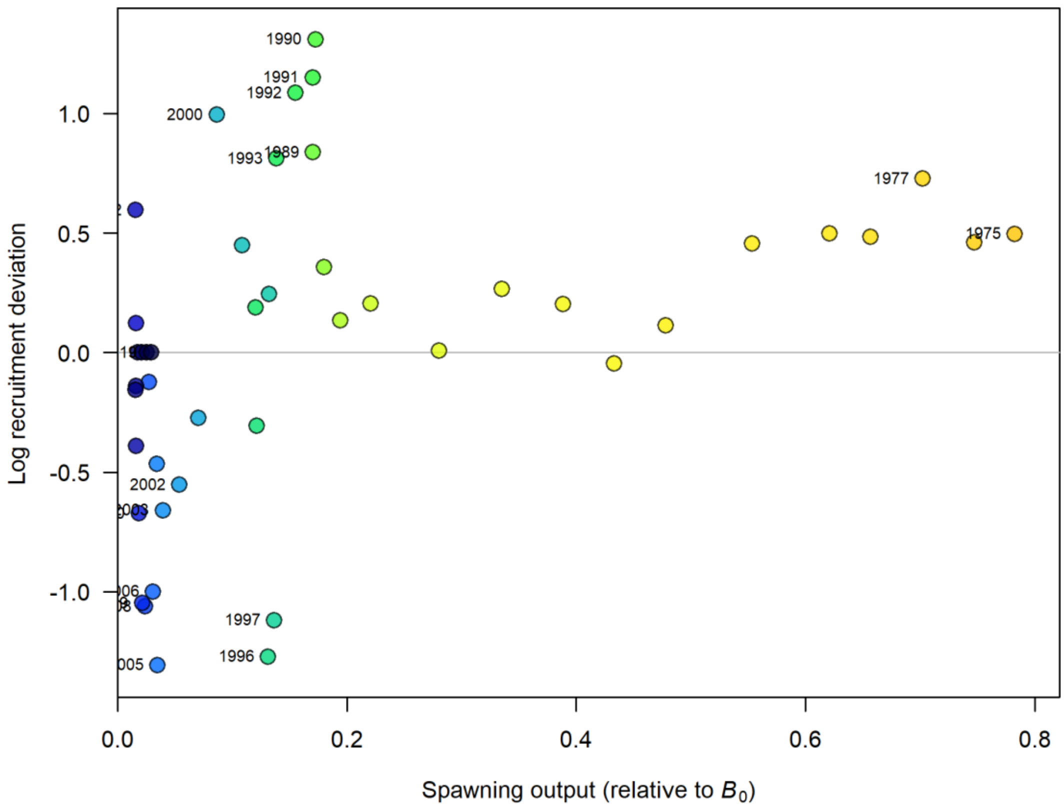
It has also become apparent that length data collected as part of a research project in NSW between 1993 and 1997 is not currently included in the assessment (Liggins et al., 1997). Further investigations are required to locate these data and incorporate them into future assessments where possible. Limited information on the location of each record will need to be resolved before these data can be included in data processing prior to inclusion in the assessment.

# Appendix A

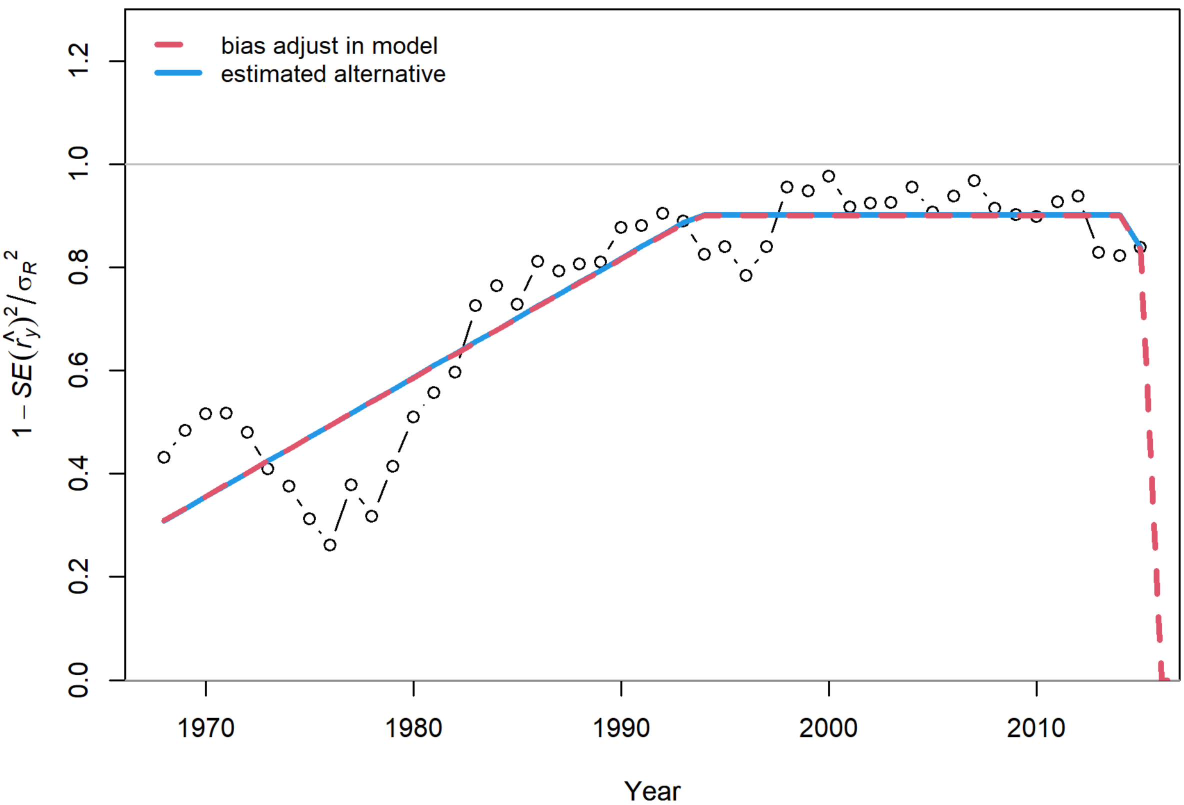
## A.1 Base case model diagnostics



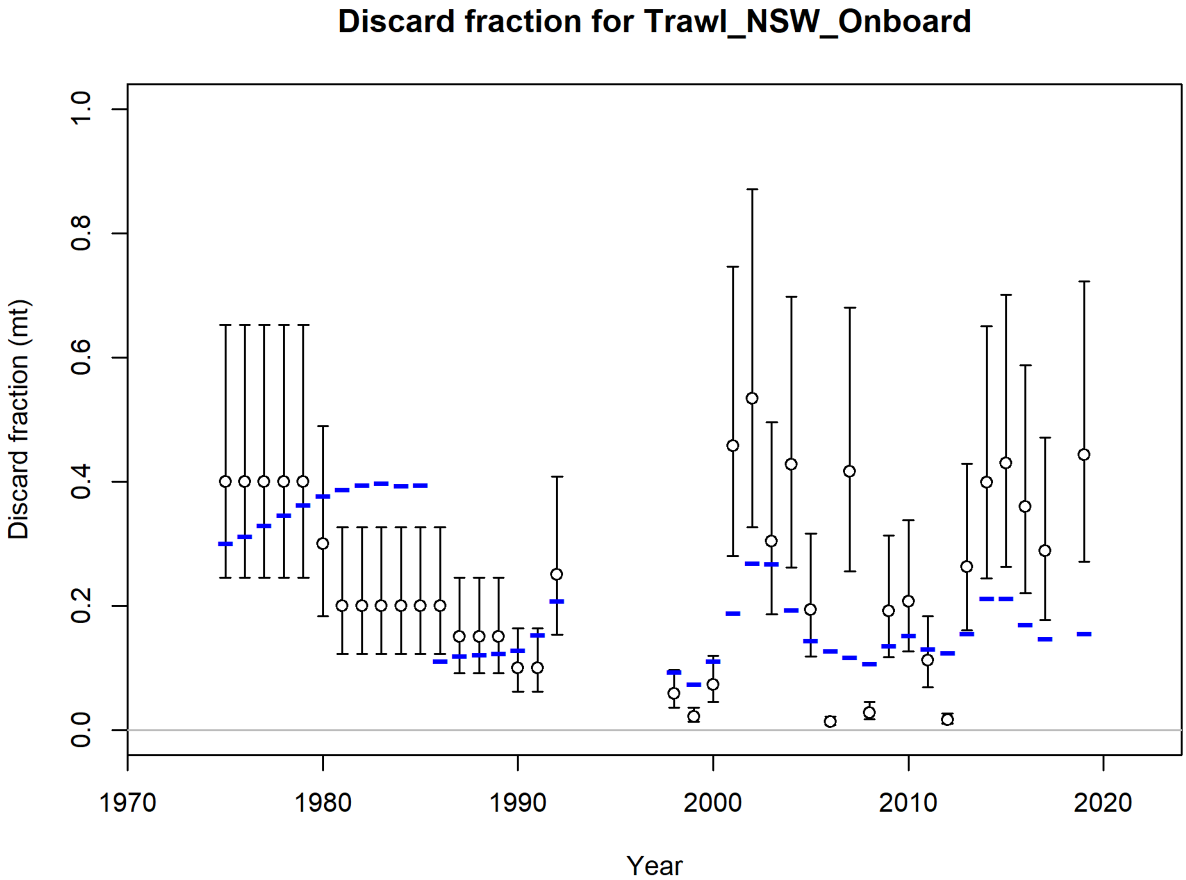

**Apx Figure A.1 Landings and estimated discards for Redfish.**

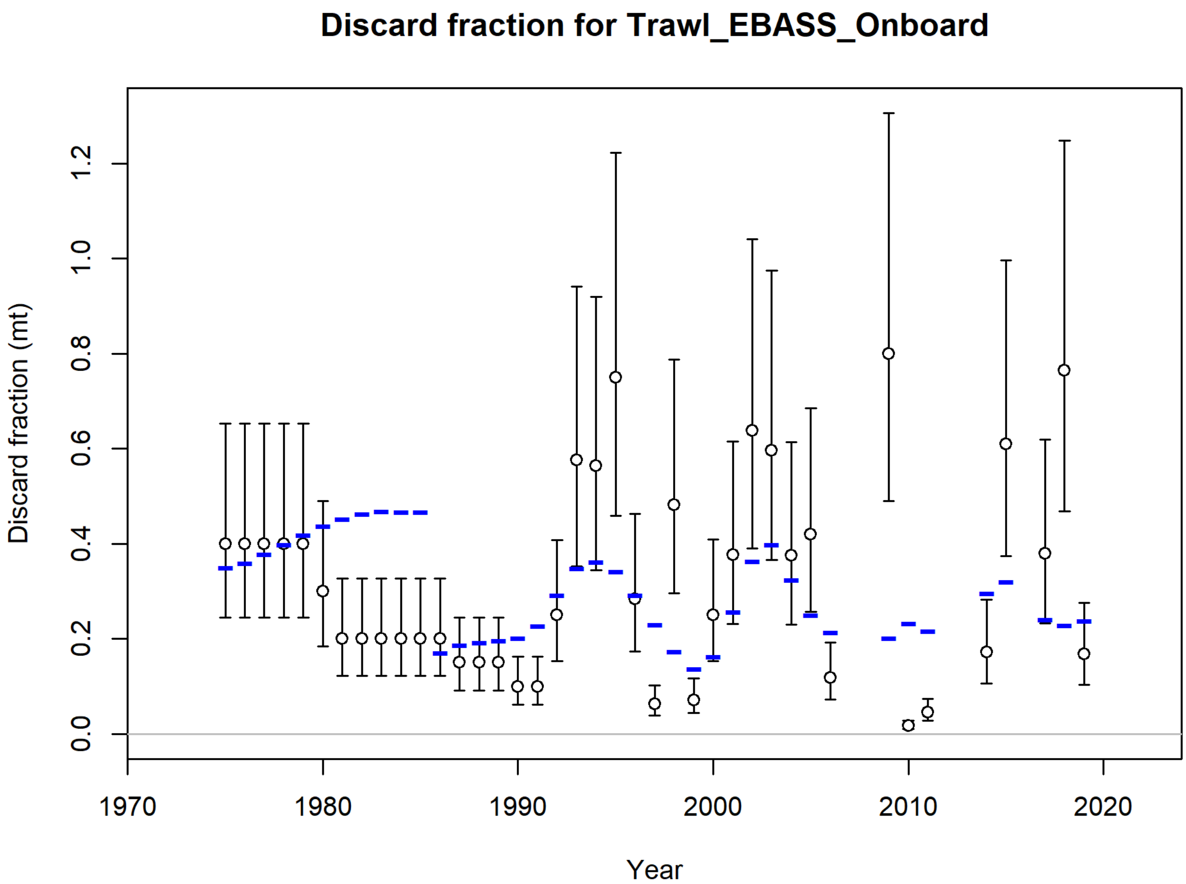



**Apx Figure A.2 Stock recruitment curve deviations for Redfish.**

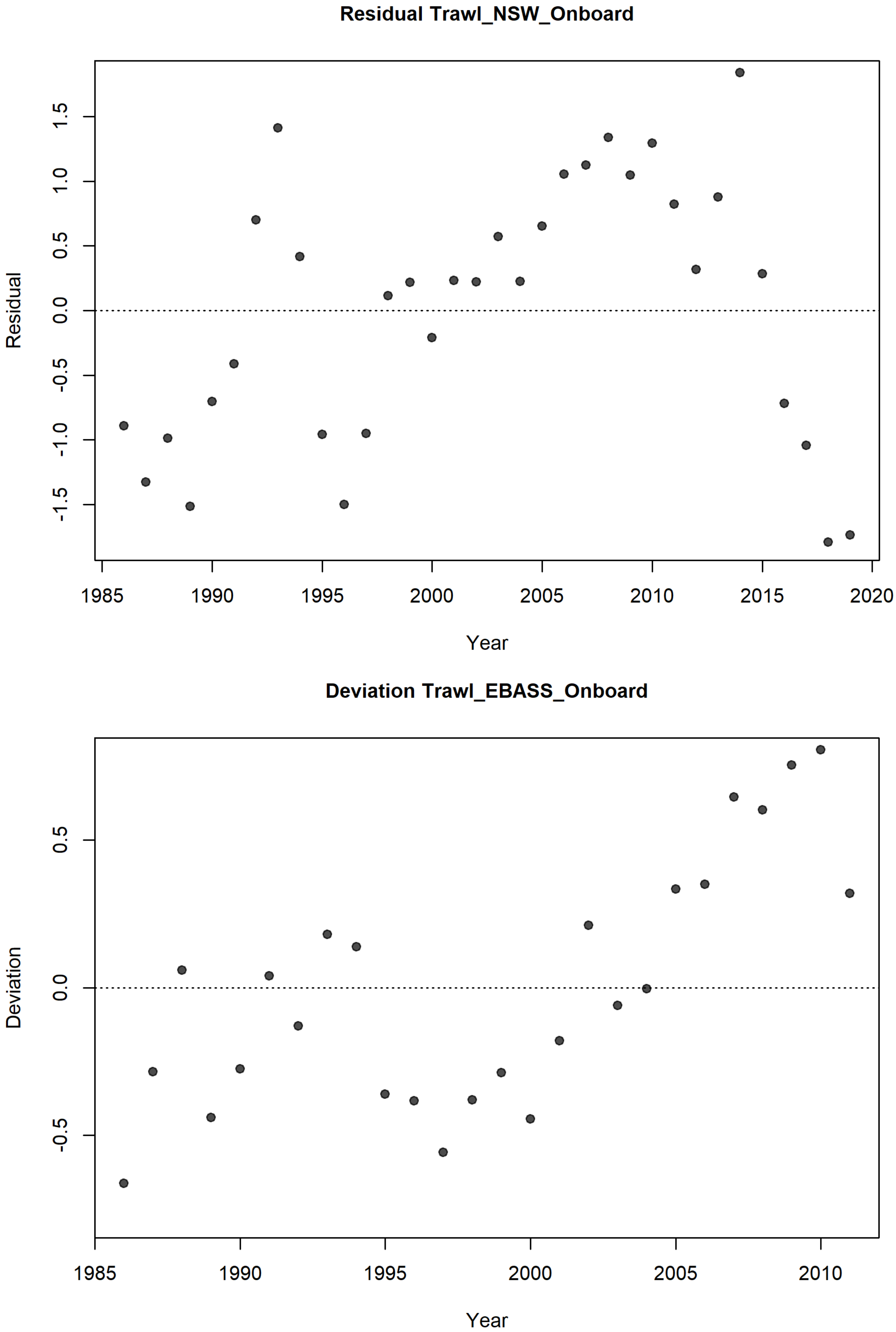



**Apx Figure A.3 Recruitment bias ramp adjustment for Redfish.**

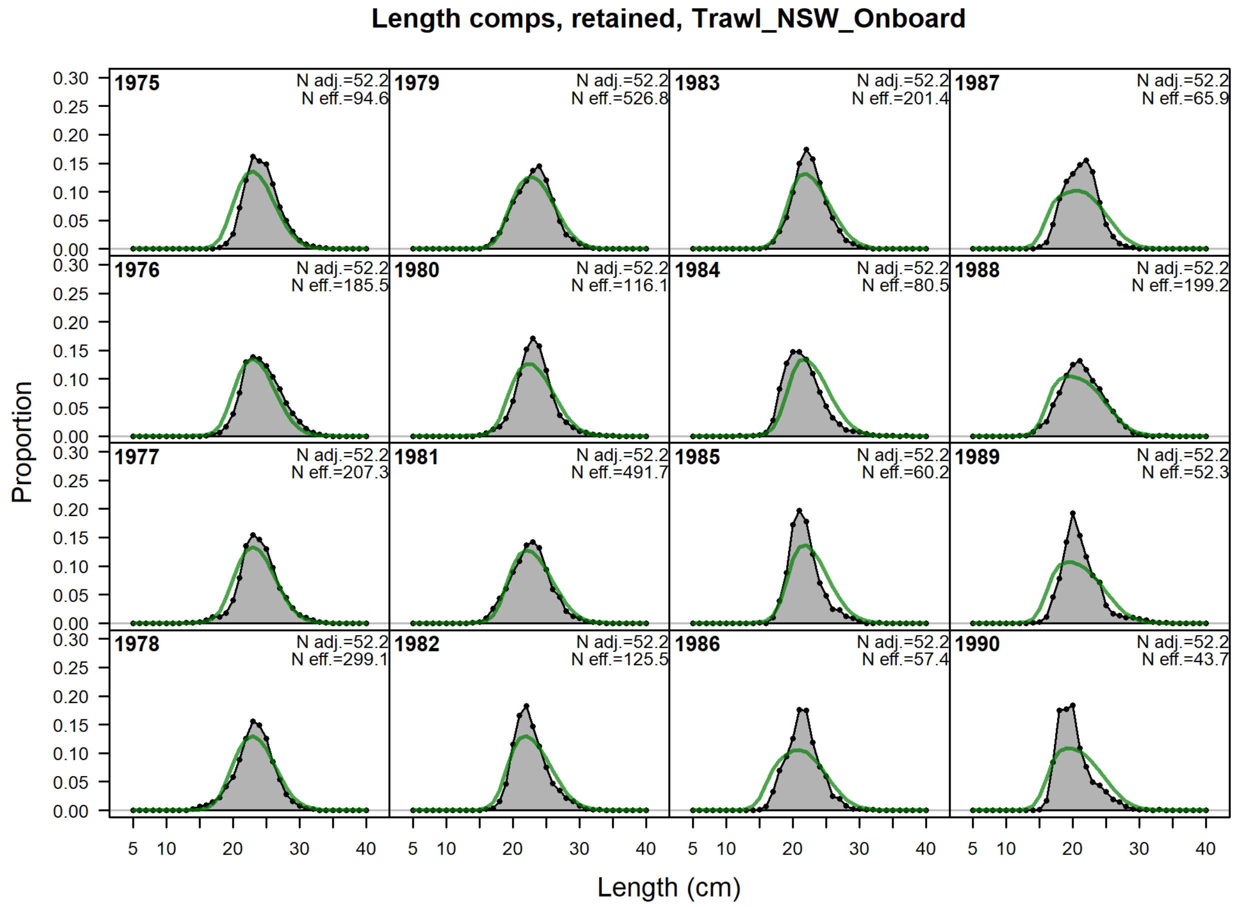


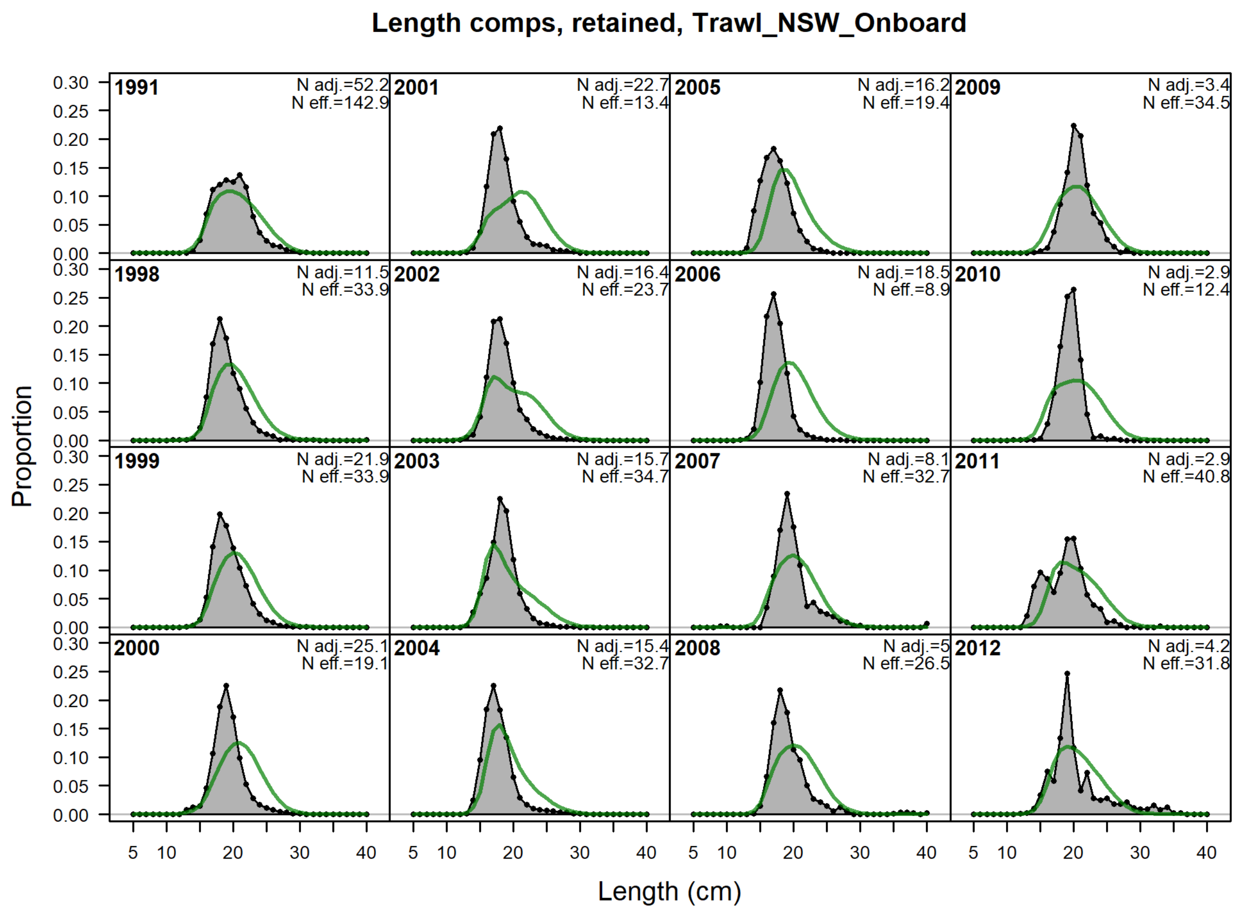



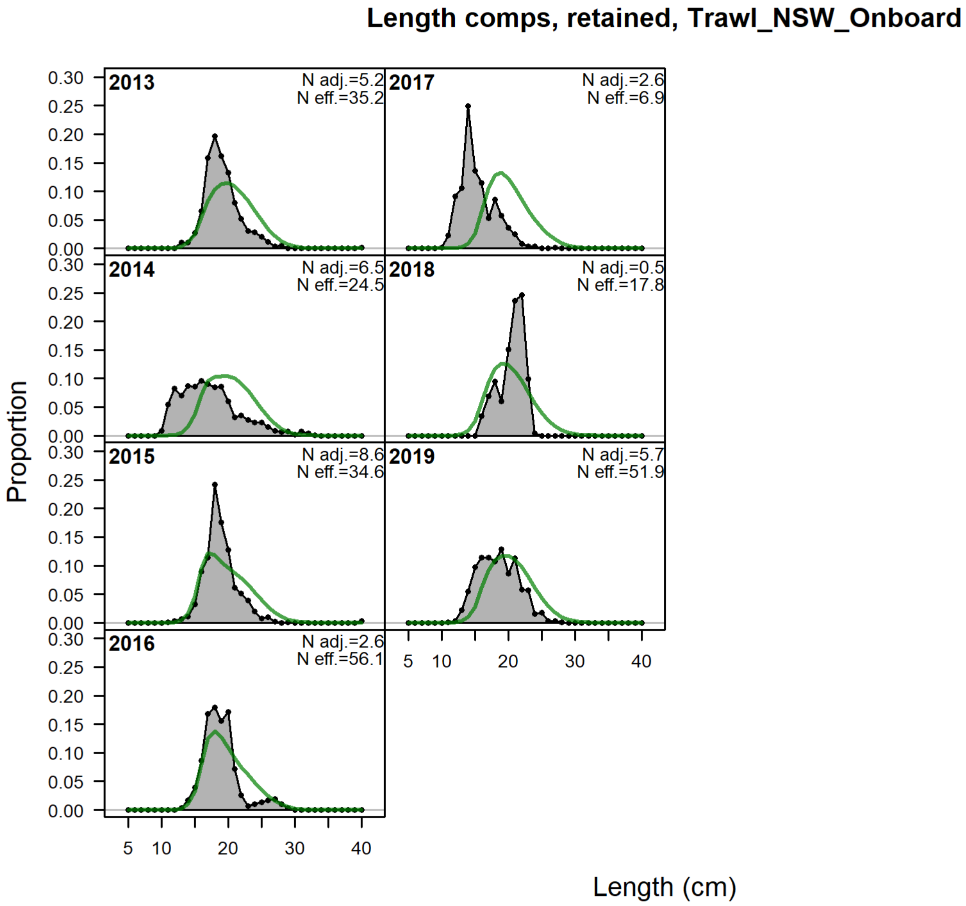

**Apx Figure A.4 Fits to trawl discards in both NSW and EBASS for Redfish.**



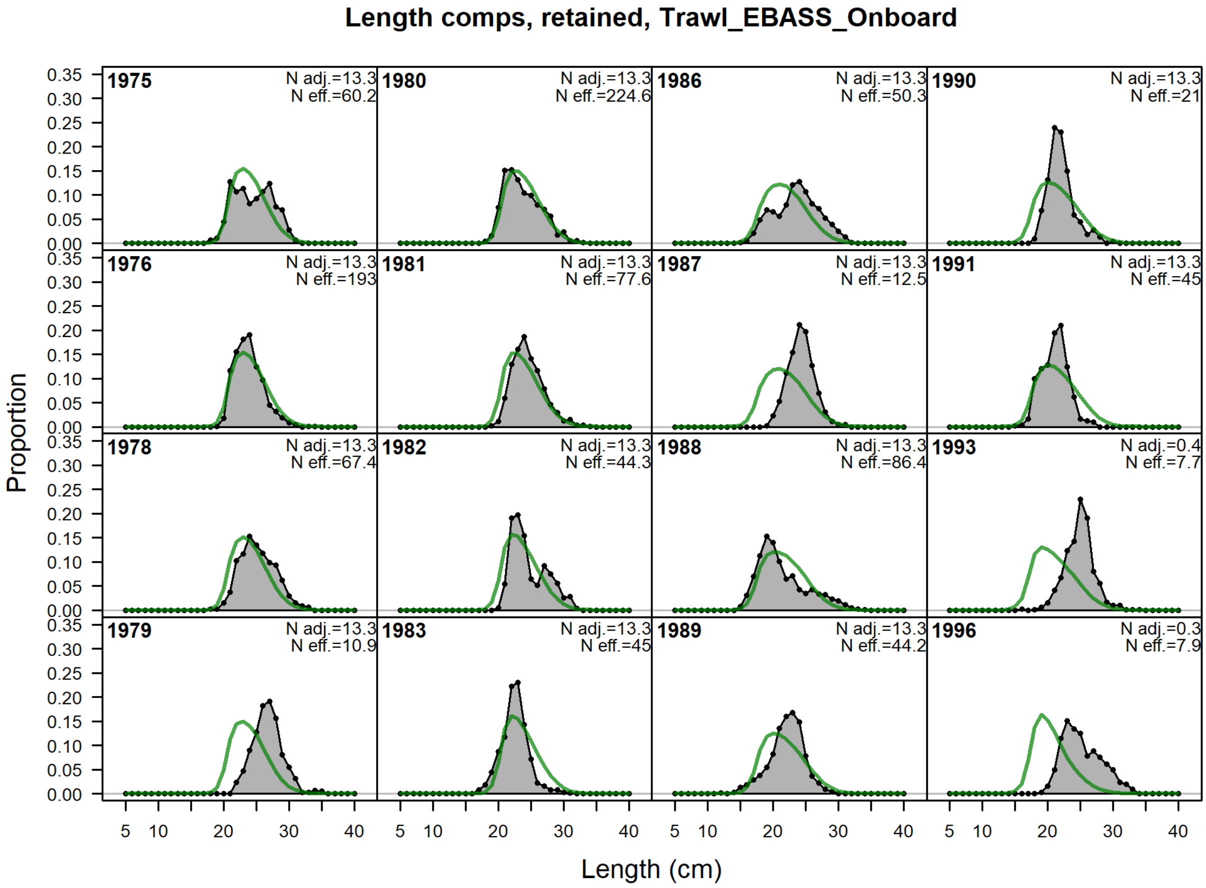

**Apx Figure A.5 Residuals for fits to CPUE in both NSW and EBASS for Redfish.**

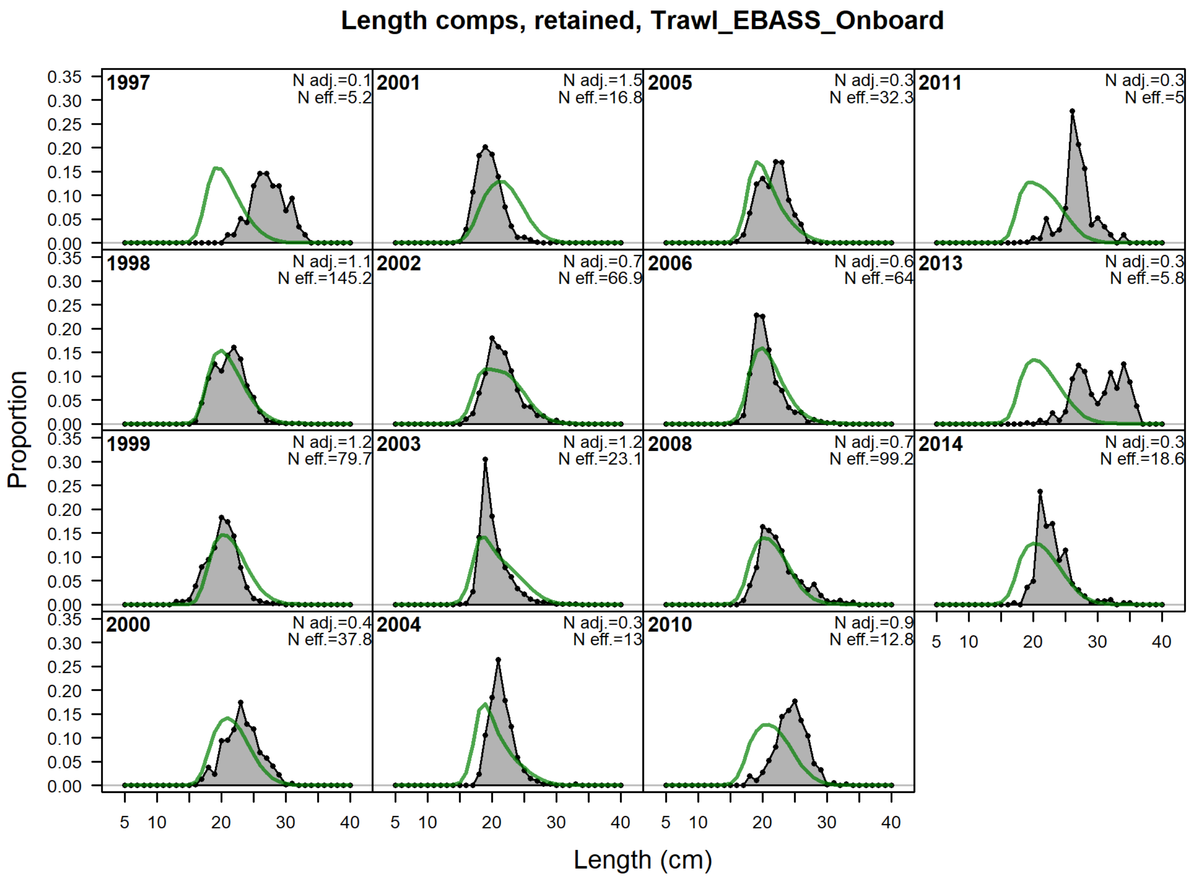

Length comps, retained, Trawl_NSW_Onboard
1975 N adj.=52.2 N eff.=94.6
1976 N adj.=52.2 N eff.=185.5
1977 N adj.=52.2 N eff.=207.3
1978 N adj.=52.2 N eff.=299.1
1979 N adj.=52.2 N eff.=526.8
1980 N adj.=52.2 N eff.=116.1
1981 N adj.=52.2 N eff.=491.7
1982 N adj.=52.2 N eff.=125.5
1983 N adj.=52.2 N eff.=201.4
1984 N adj.=52.2 N eff.=80.5
1985 N adj.=52.2 N eff.=60.2
1986 N adj.=52.2 N eff.=57.4
1987 N adj.=52.2 N eff.=65.9
1988 N adj.=52.2 N eff.=199.2
1989 N adj.=52.2 N eff.=52.3
1990 N adj.=52.2 N eff.=43.7
Proportion
Length (cm)


Length comps, retained, Trawl_NSW_Onboard
1991 N adj.=52.2 N eff.=142.9
1998 N adj.=11.5 N eff.=33.9
1999 N adj.=21.9 N eff.=33.9
2000 N adj.=25.1 N eff.=19.1
2001 N adj.=22.7 N eff.=13.4
2002 N adj.=16.4 N eff.=23.7
2003 N adj.=15.7 N eff.=34.7
2004 N adj.=15.4 N eff.=32.7
2005 N adj.=16.2 N eff.=19.4
2006 N adj.=18.5 N eff.=8.9
2007 N adj.=8.1 N eff.=32.7
2008 N adj.=5 N eff.=26.5
2009 N adj.=3.4 N eff.=34.5
2010 N adj.=2.9 N eff.=12.4
2011 N adj.=2.9 N eff.=40.8
2012 N adj.=4.2 N eff.=31.8
Proportion
Length (cm)

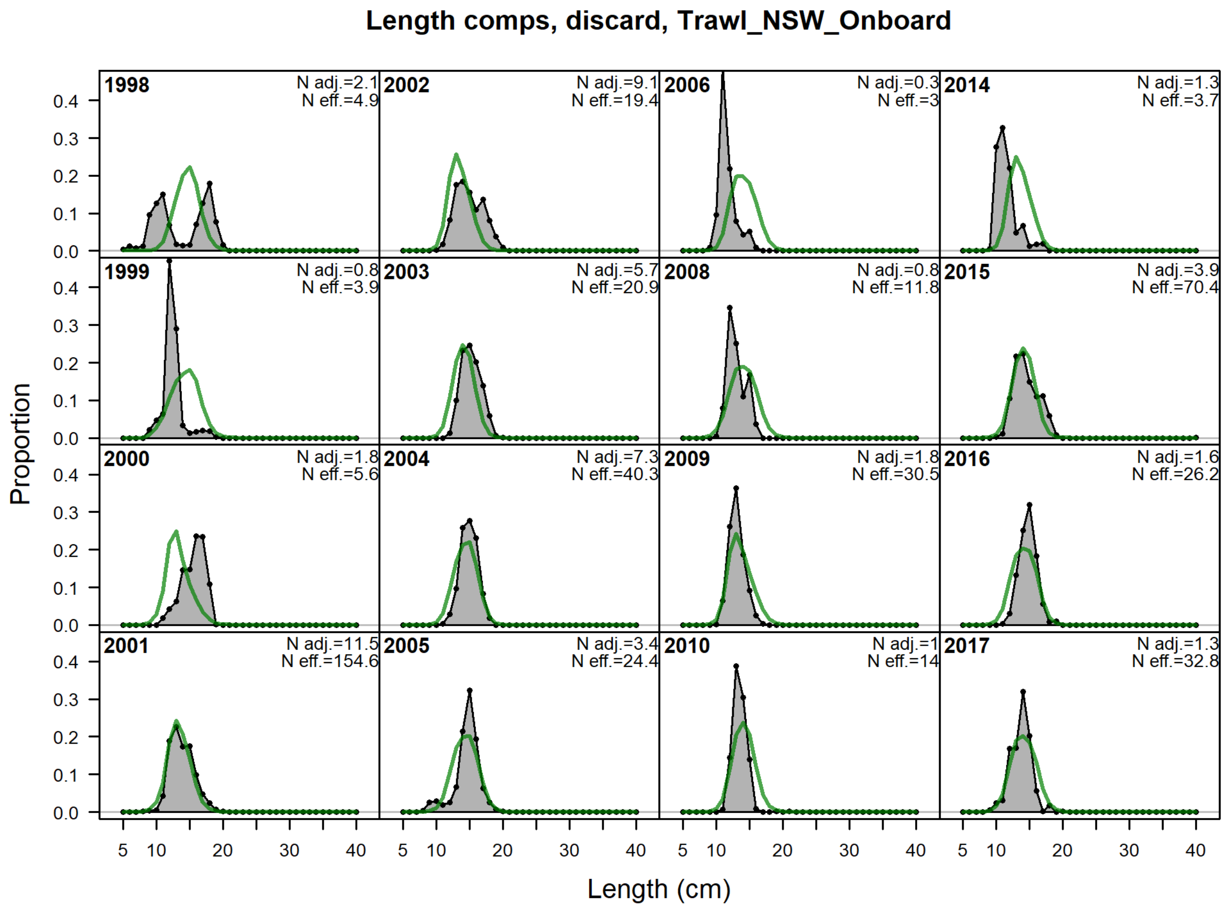


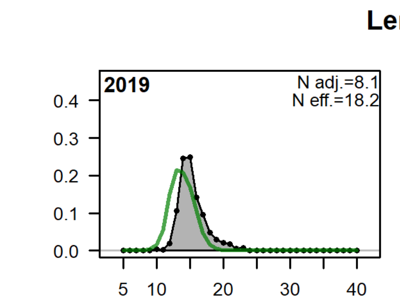

**Apx Figure A.6 Redfish length composition fits: NSW onboard trawl retained.**



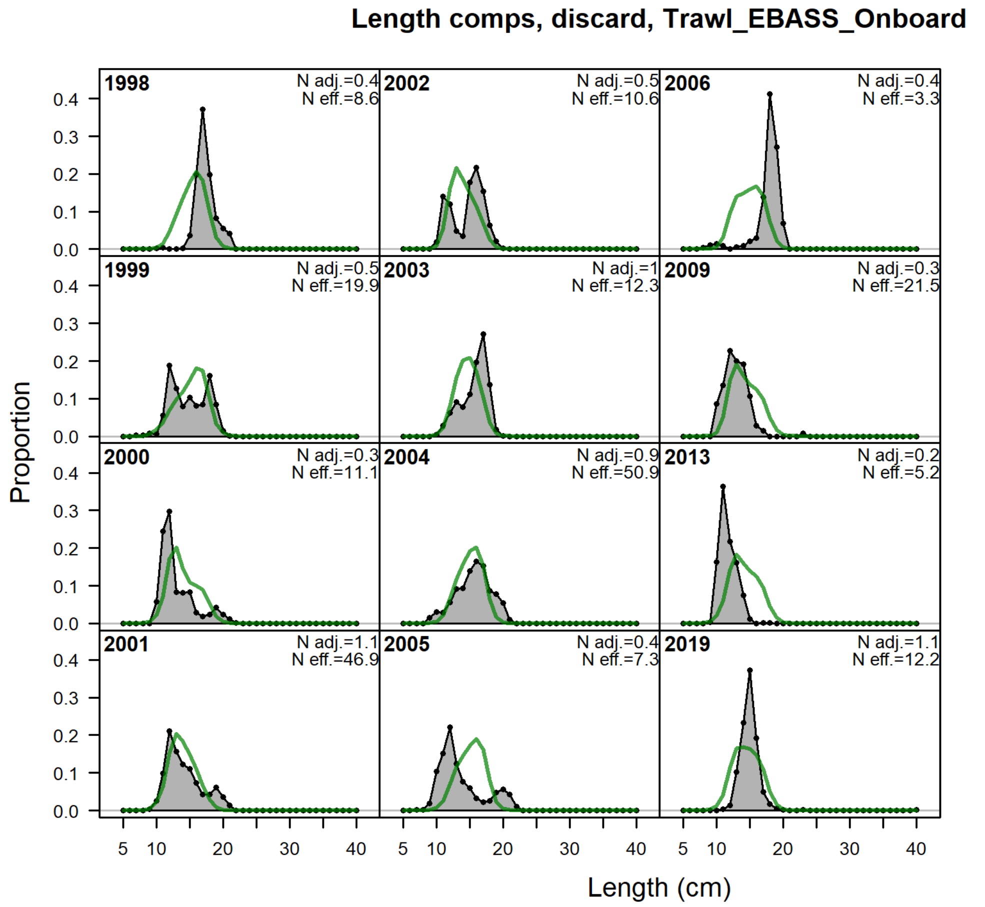




**Apx Figure A.7 Redfish length composition fits: EBASS onboard trawl retained.**

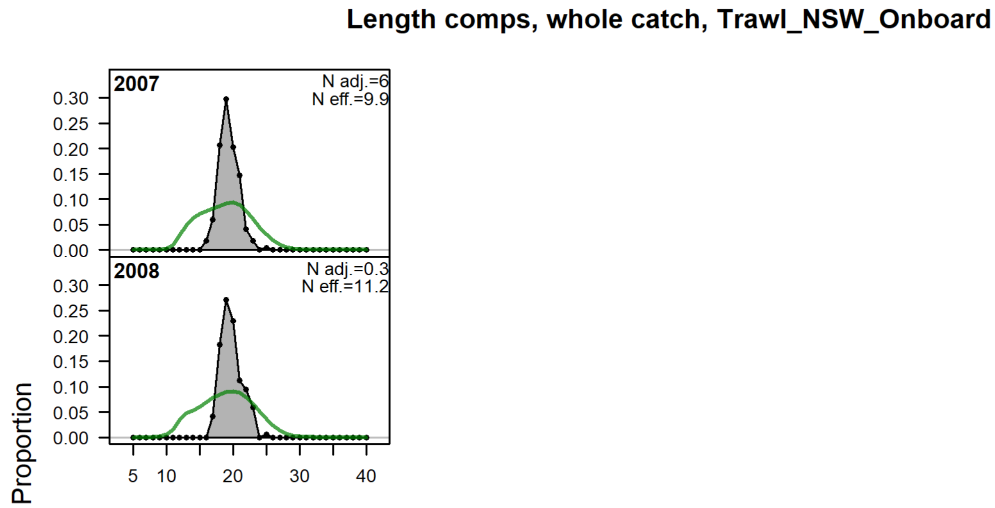


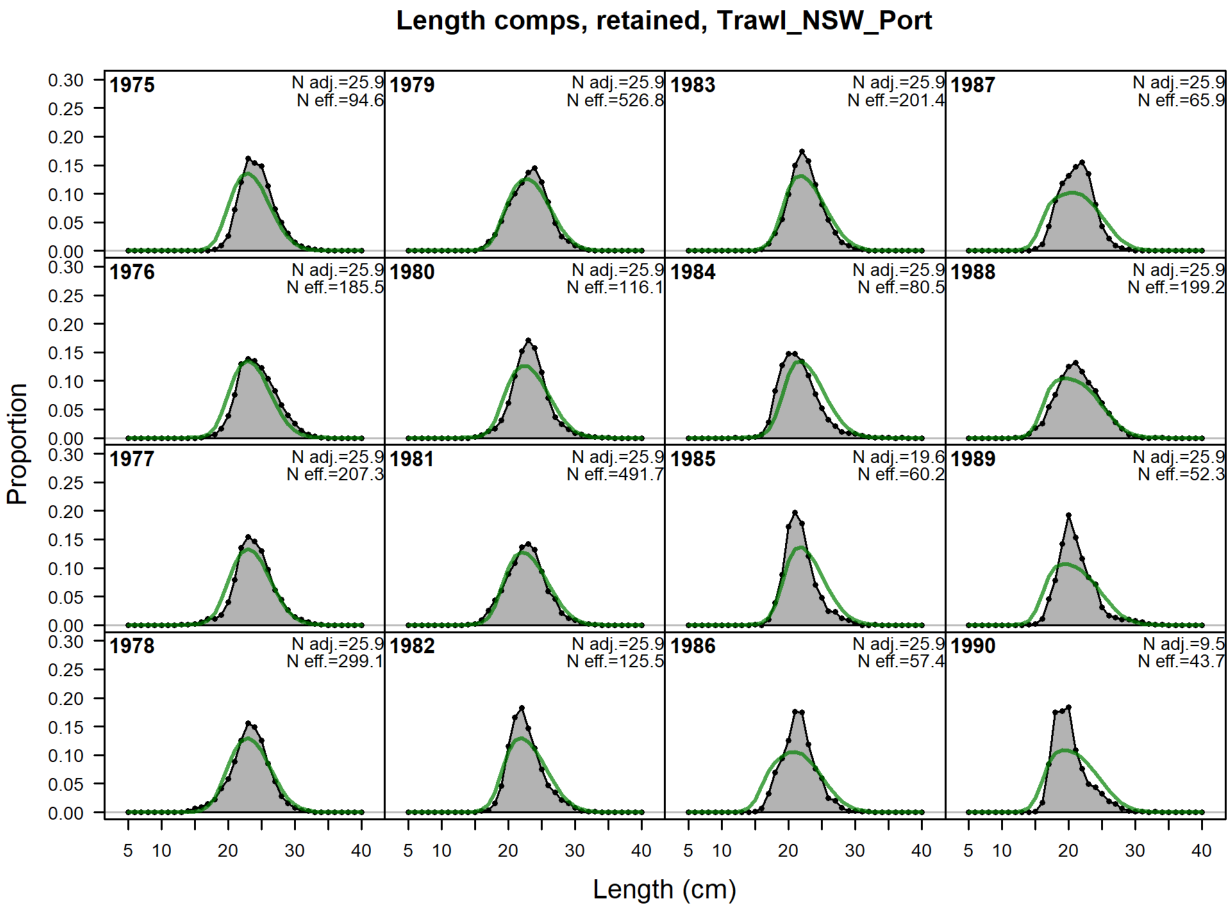

**Apx Figure A.8 Redfish length composition fits: NSW onboard trawl discard.**

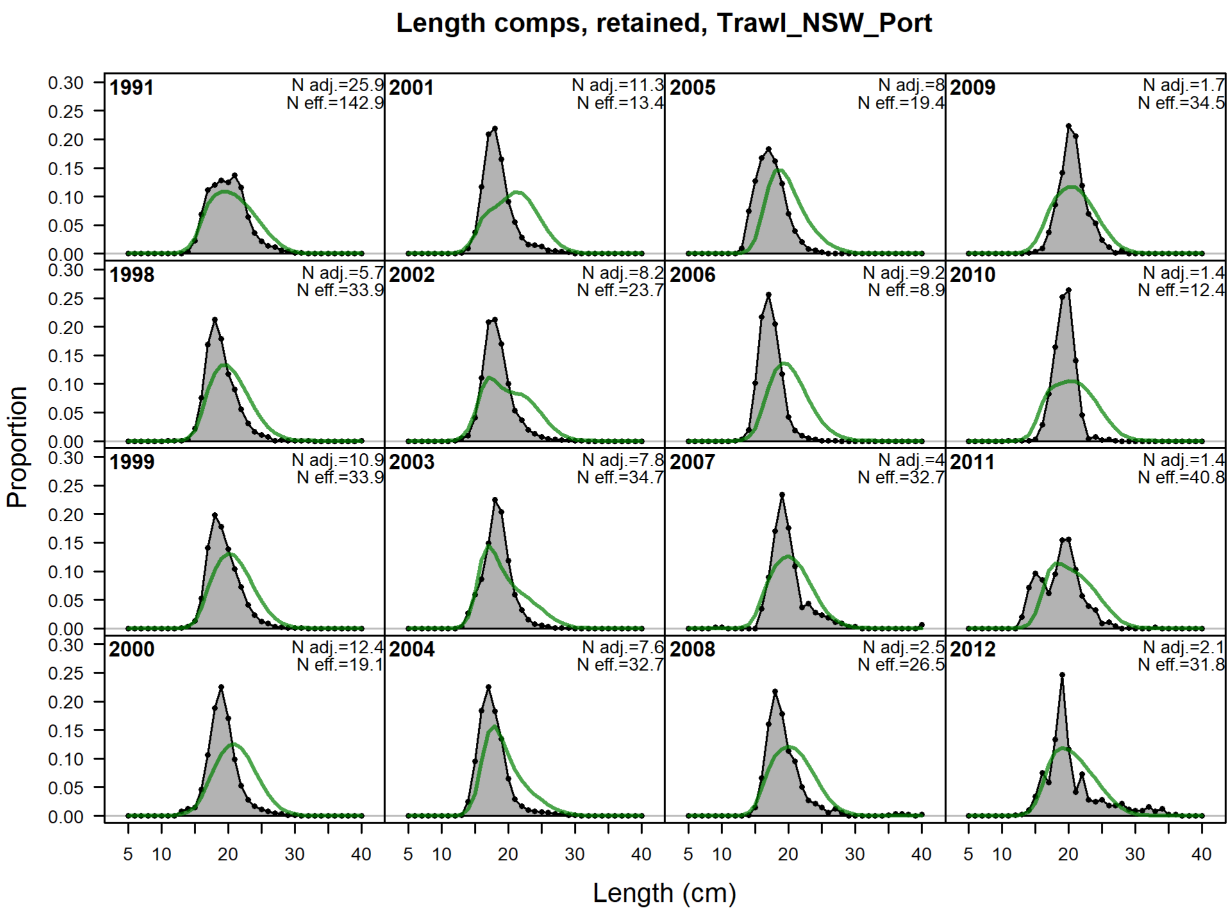


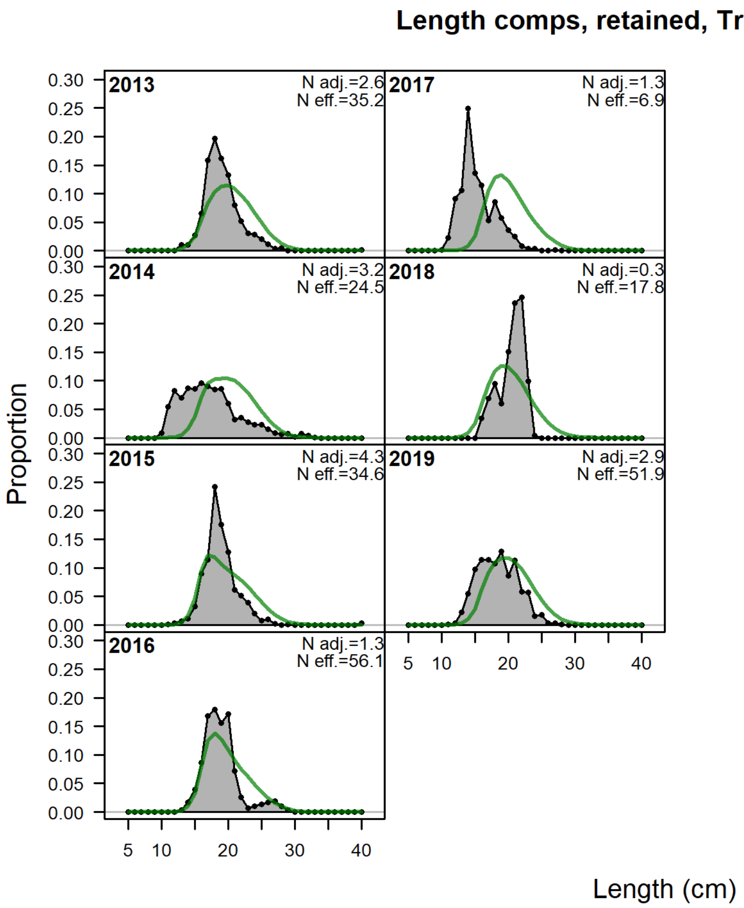

Apx Figure A.9 Redfish length composition fits: EBASS onboard trawl discard.



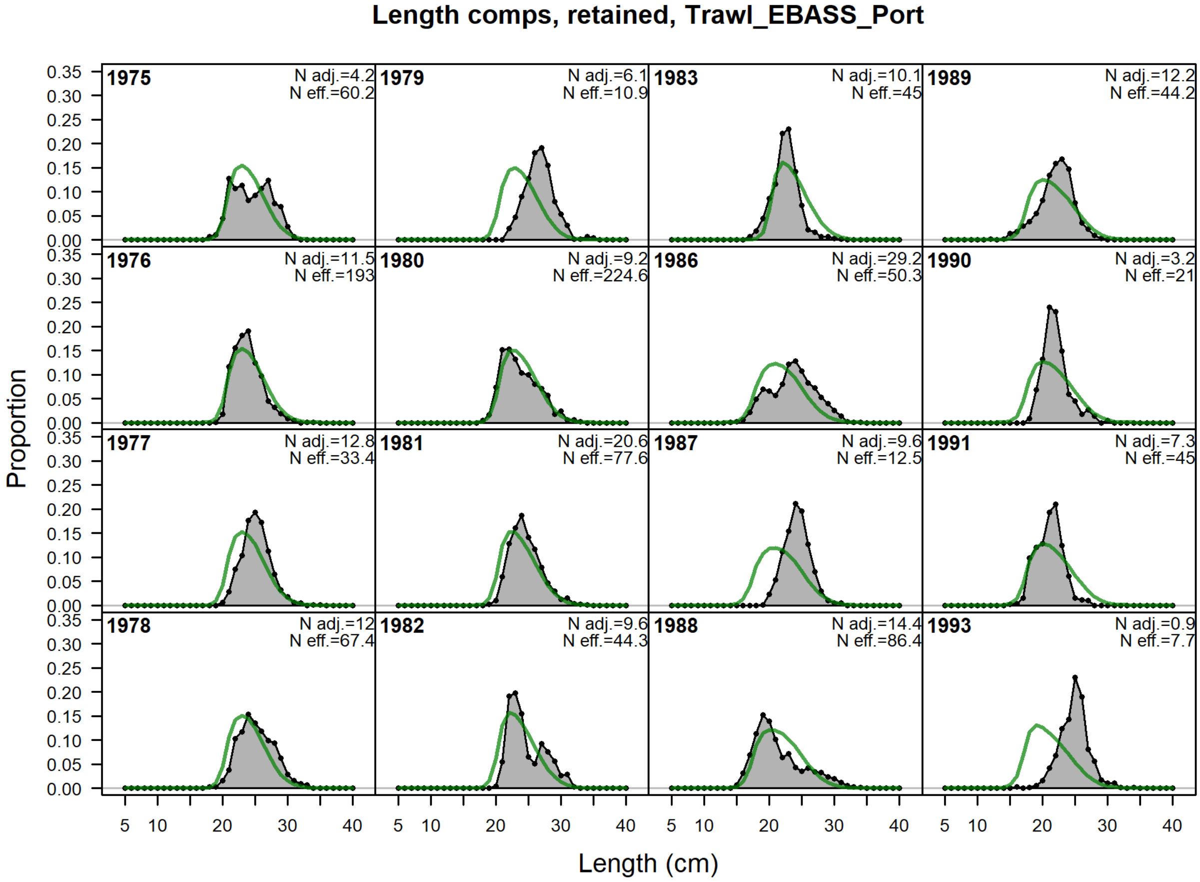

Apx Figure A.10 Redfish length composition fits: NSW onboard trawl combined retained and discard.

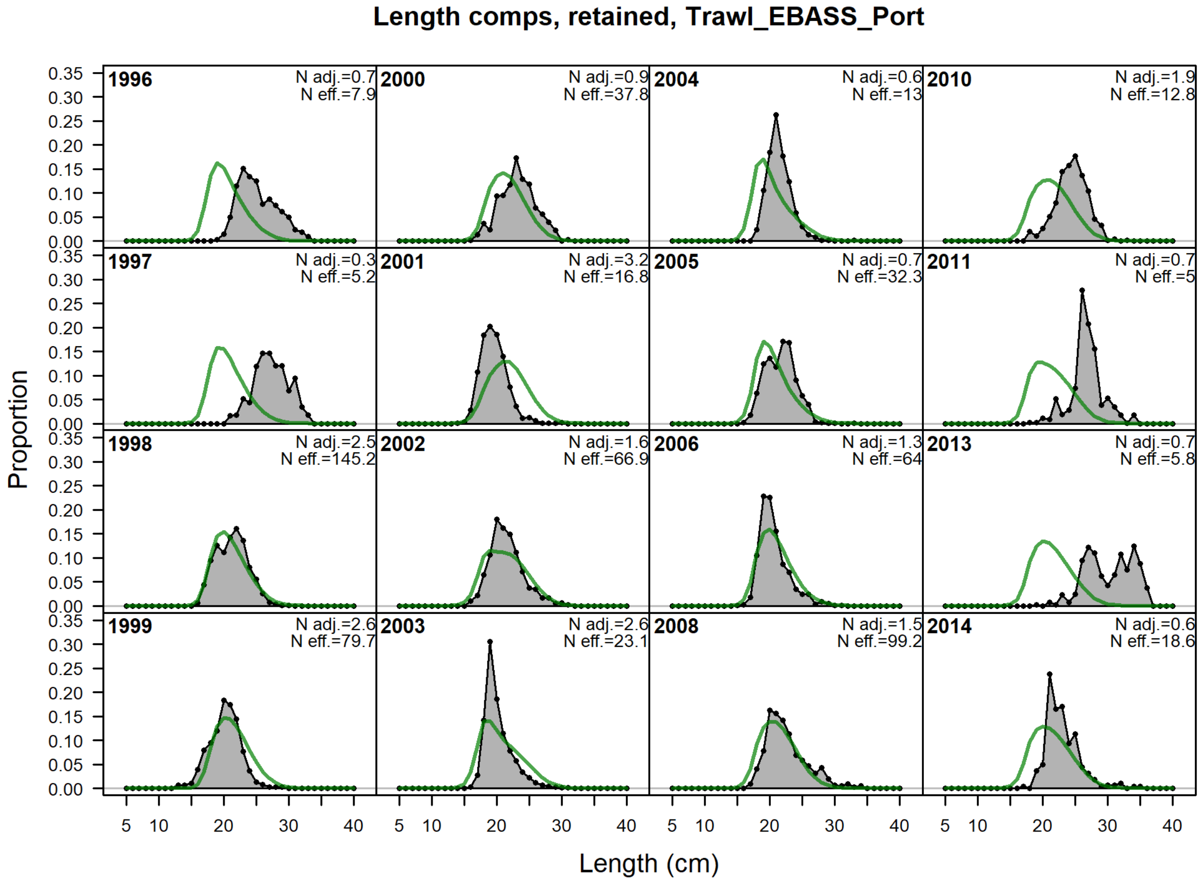

Length comps, retained, Trawl_NSW_Port
Proportion
Length (cm)
1975 N adj.=25.9 N eff.=94.6
1979 N adj.=25.9 N eff.=526.8
1983 N adj.=25.9 N eff.=201.4
1987 N adj.=25.9 N eff.=65.9
1976 N adj.=25.9 N eff.=185.5
1980 N adj.=25.9 N eff.=116.1
1984 N adj.=25.9 N eff.=80.5
1988 N adj.=25.9 N eff.=199.2
1977 N adj.=25.9 N eff.=207.3
1981 N adj.=25.9 N eff.=491.7
1985 N adj.=19.6 N eff.=60.2
1989 N adj.=25.9 N eff.=52.3
1978 N adj.=25.9 N eff.=299.1
1982 N adj.=25.9 N eff.=125.5
1986 N adj.=25.9 N eff.=57.4
1990 N adj.=9.5 N eff.=43.7


Length comps, retained, Trawl_NSW_Port
Proportion
Length (cm)
1991 N adj.=25.9 N eff.=142.9
2001 N adj.=11.3 N eff.=13.4
2005 N adj.=8 N eff.=19.4
2009 N adj.=1.7 N eff.=34.5
1998 N adj.=5.7 N eff.=33.9
2002 N adj.=8.2 N eff.=23.7
2006 N adj.=9.2 N eff.=8.9
2010 N adj.=1.4 N eff.=12.4
1999 N adj.=10.9 N eff.=33.9
2003 N adj.=7.8 N eff.=34.7
2007 N adj.=4 N eff.=32.7
2011 N adj.=1.4 N eff.=40.8
2000 N adj.=12.4 N eff.=19.1
2004 N adj.=7.6 N eff.=32.7
2008 N adj.=2.5 N eff.=26.5
2012 N adj.=2.1 N eff.=31.8

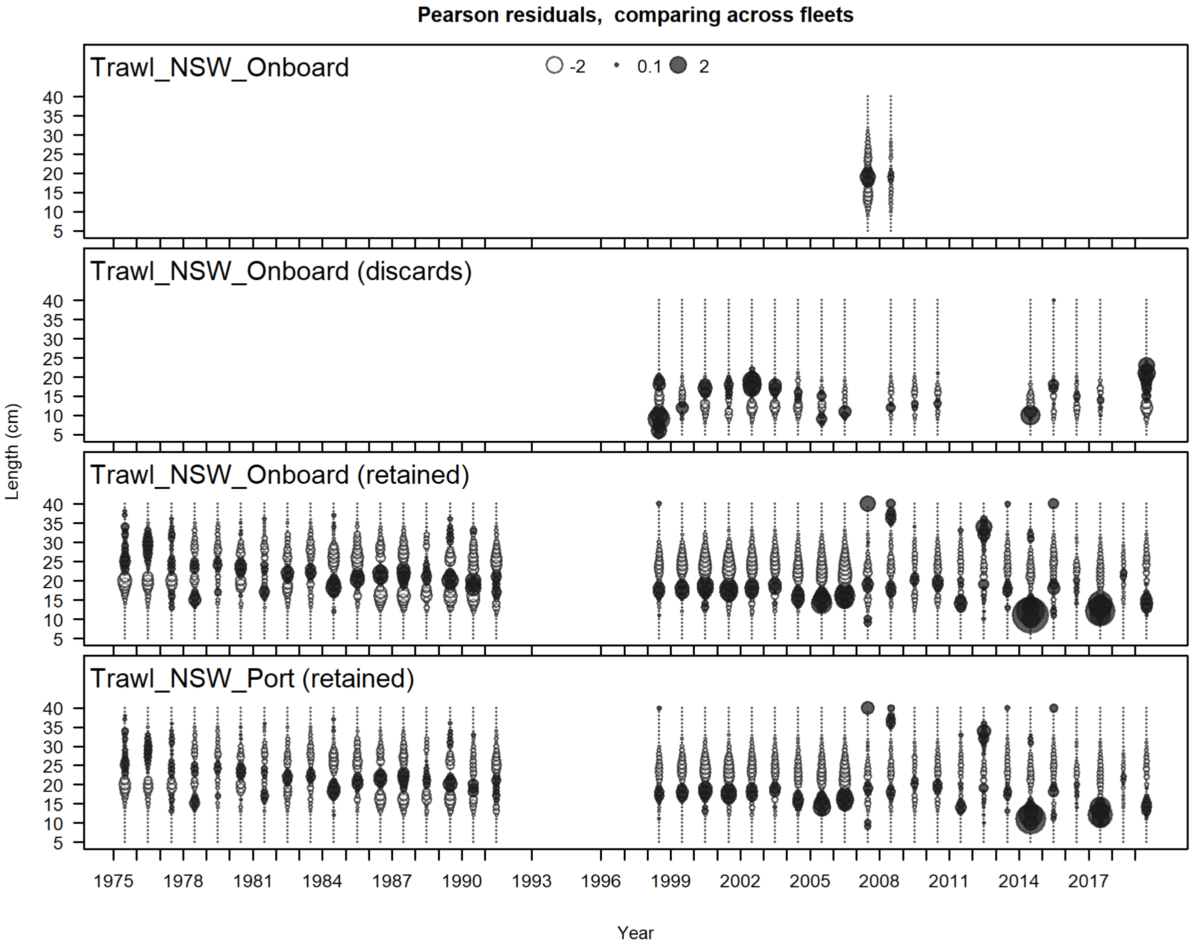



**Apx Figure A.11 Redfish length composition fits: NSW Port trawl.**

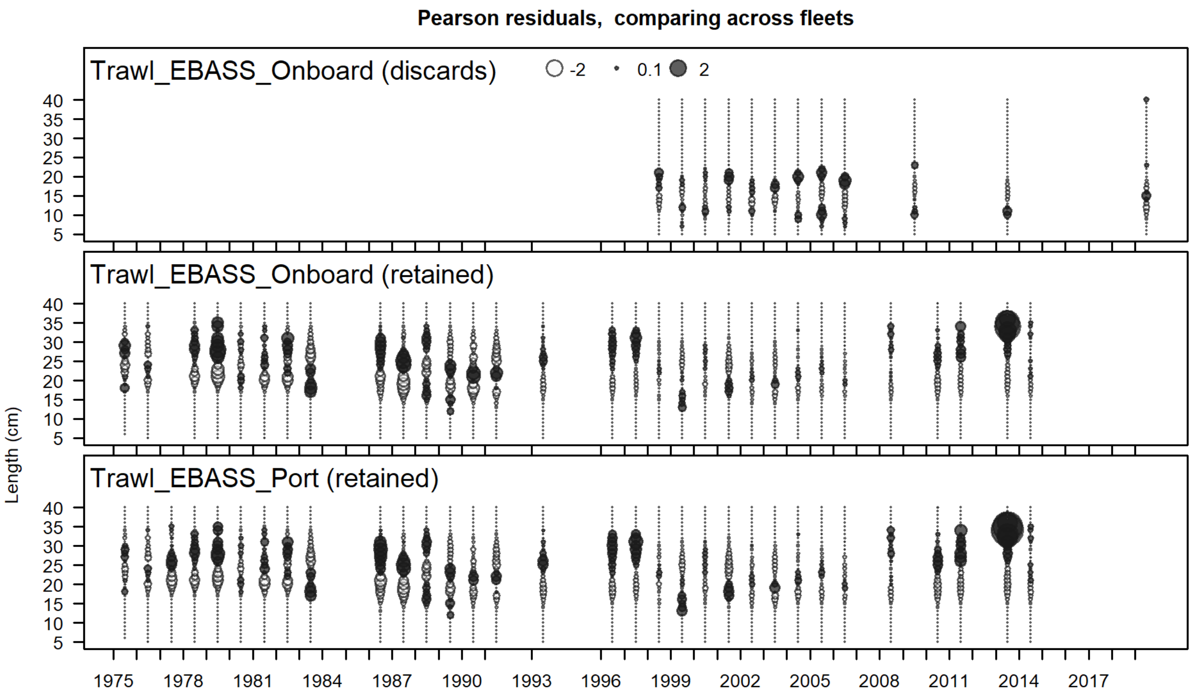


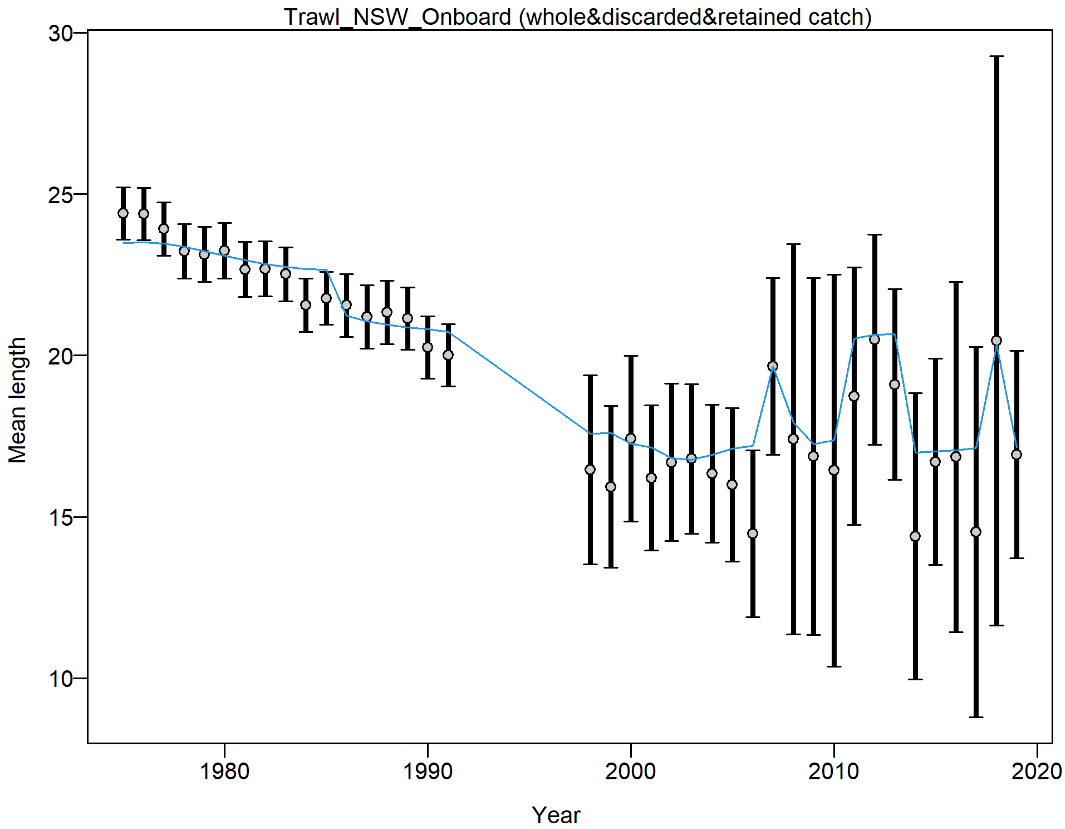

**Apx Figure A.12 Redfish length composition fits: EBASS Port trawl.**

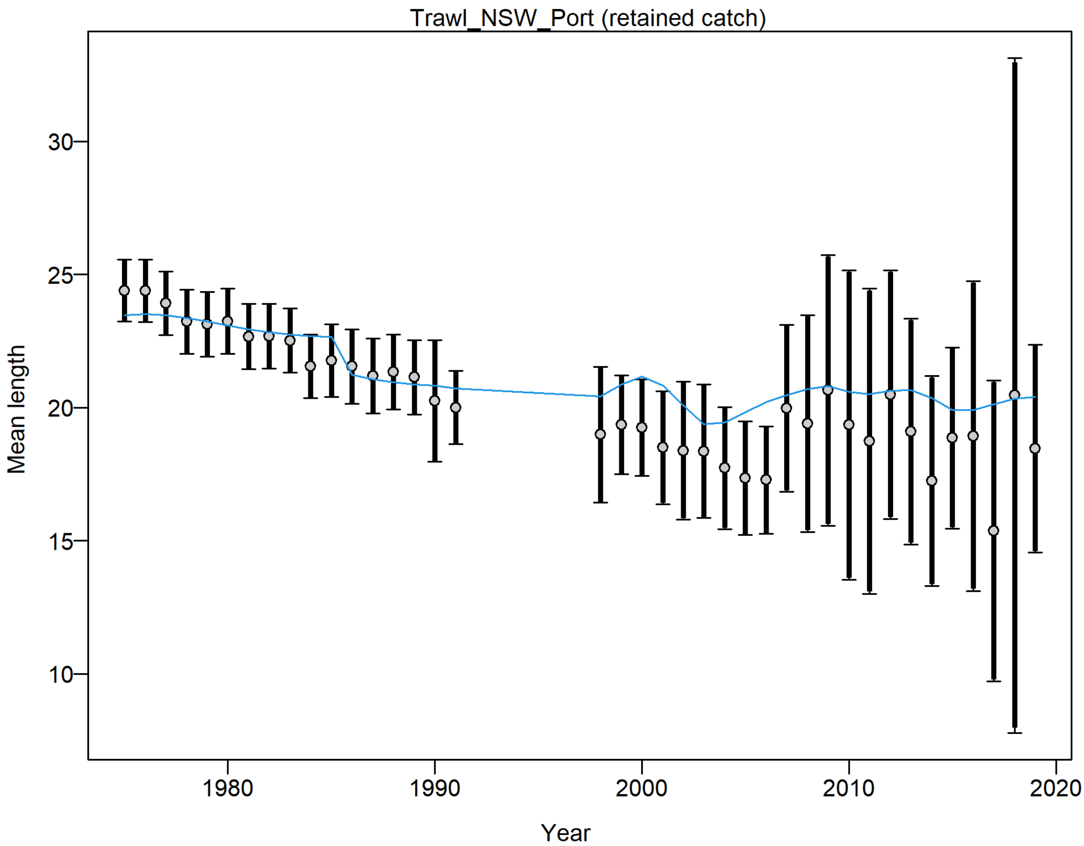



Apx Figure A.13 Residuals from the NSW annual length compositions (retained) for redfish displayed by year.

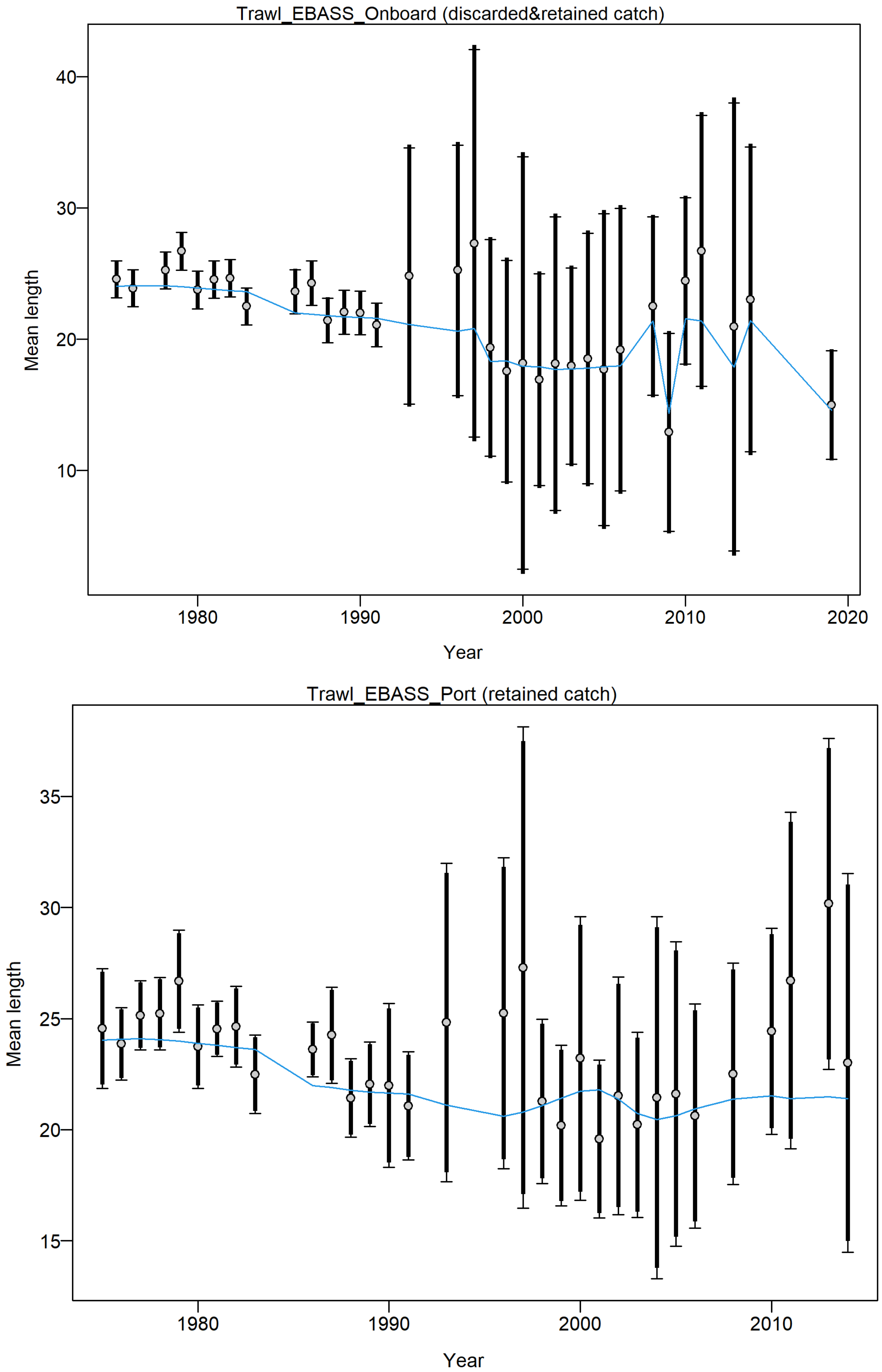



Apx Figure A.14 Residuals from the EBASS annual length compositions (retained) for redfish displayed by year.

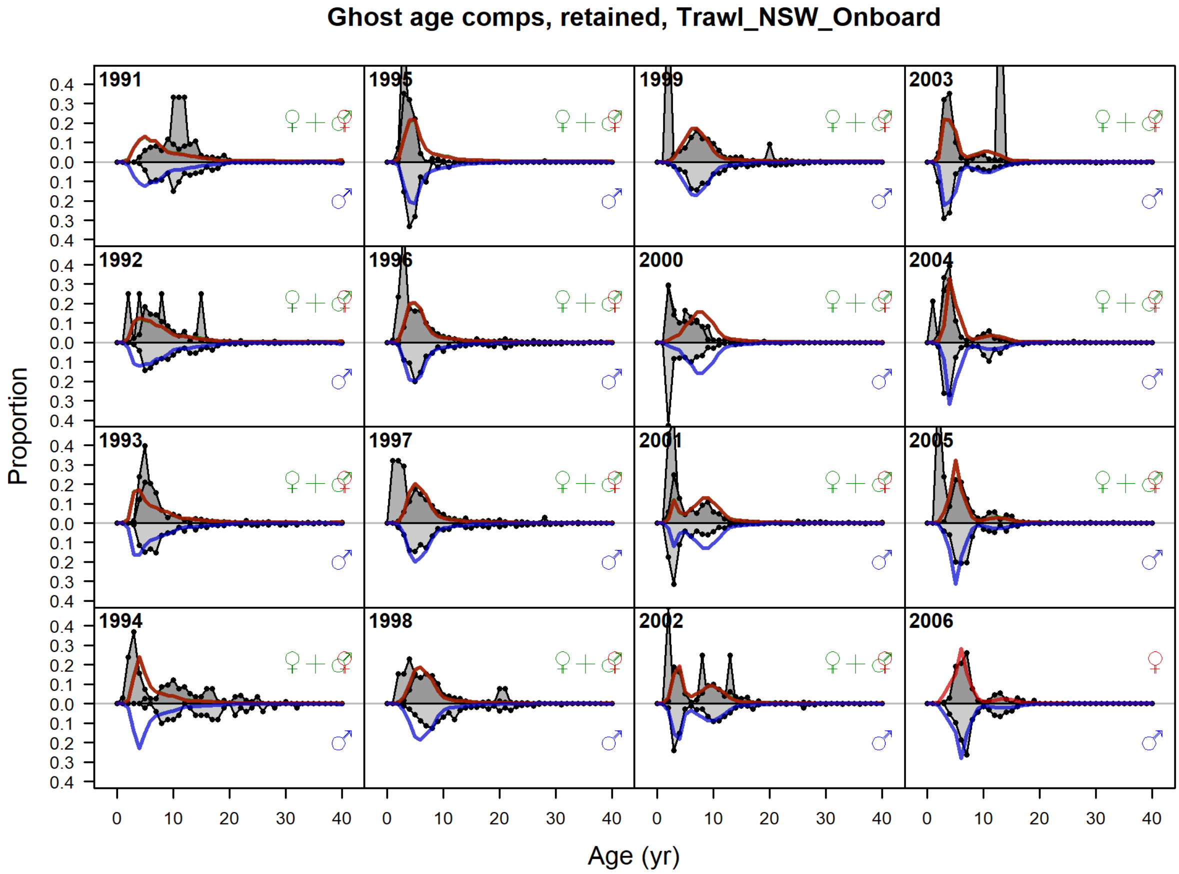


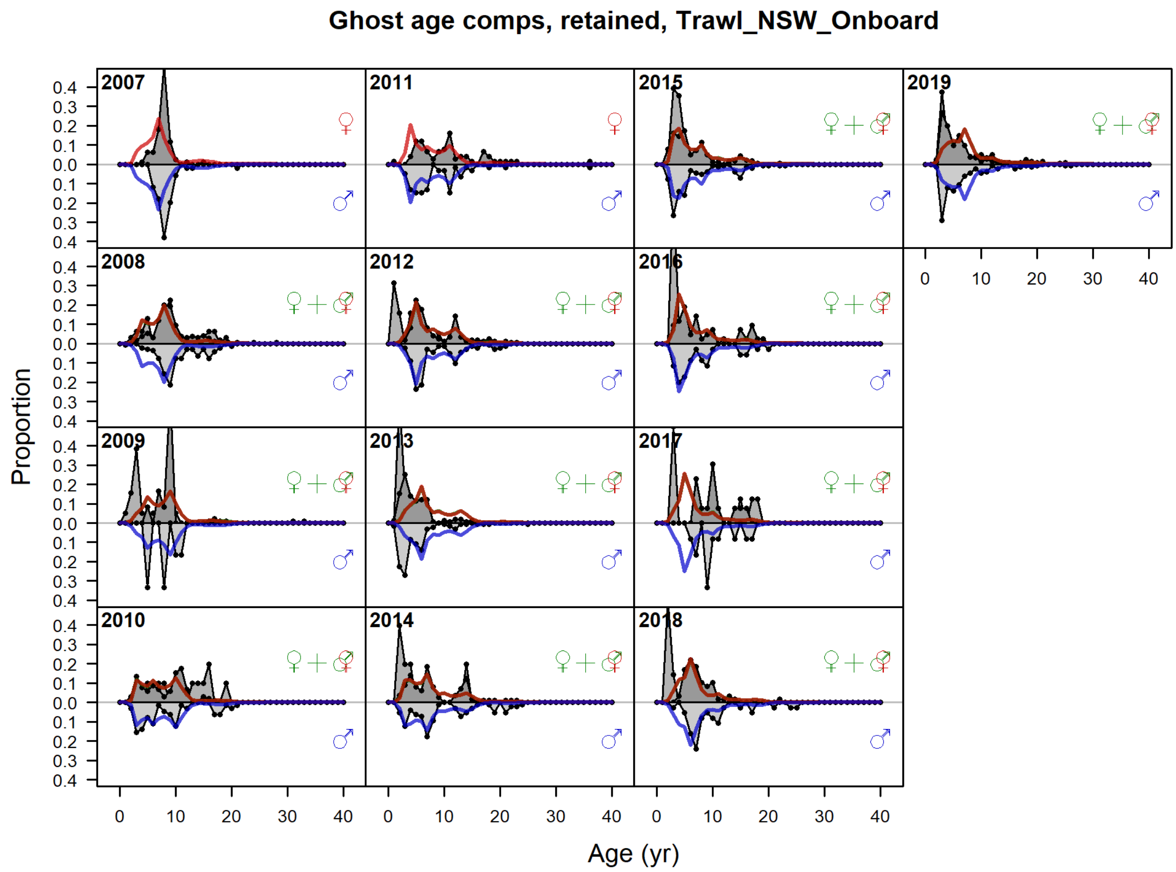




**Apx Figure A.15 Redfish NSW length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.**

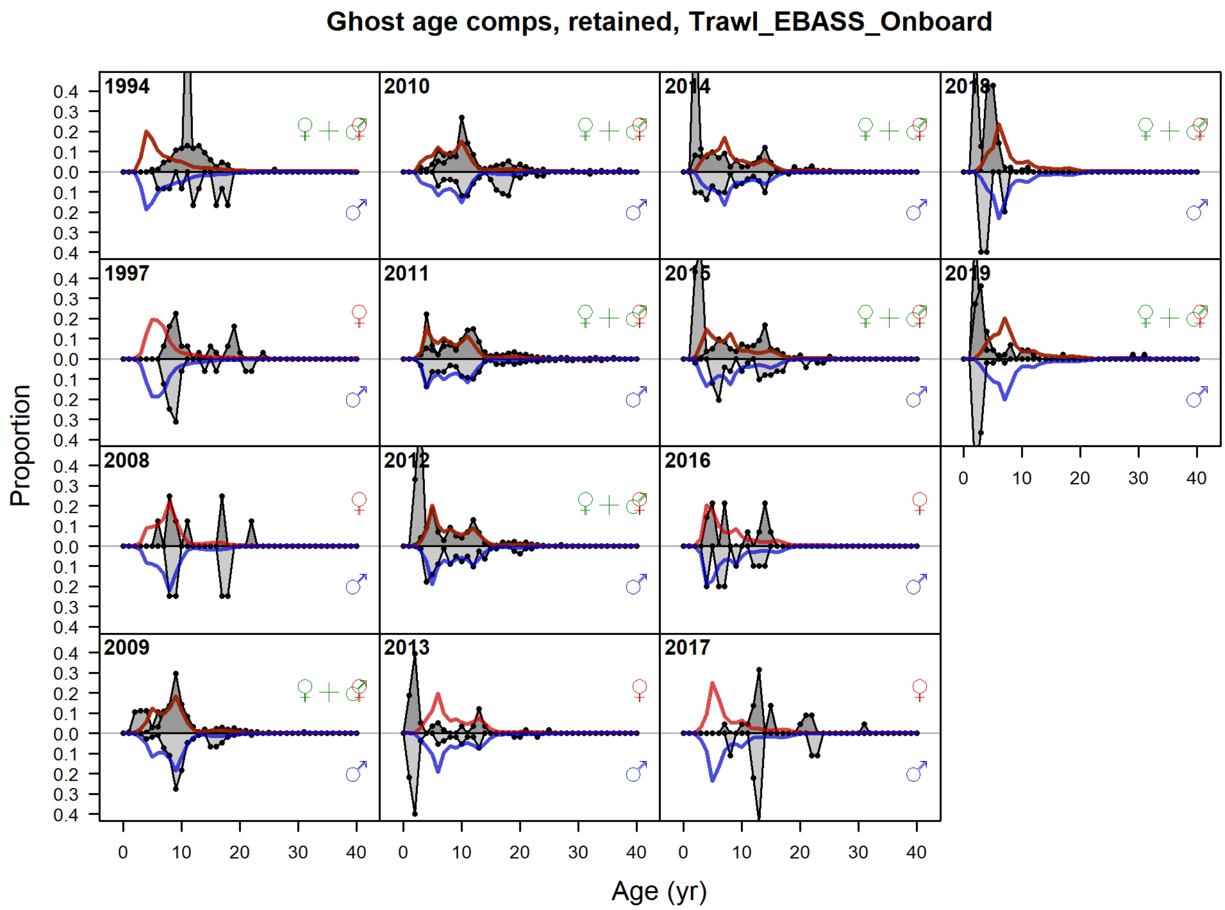



**Apx Figure A.16 Redfish EBASS length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.**

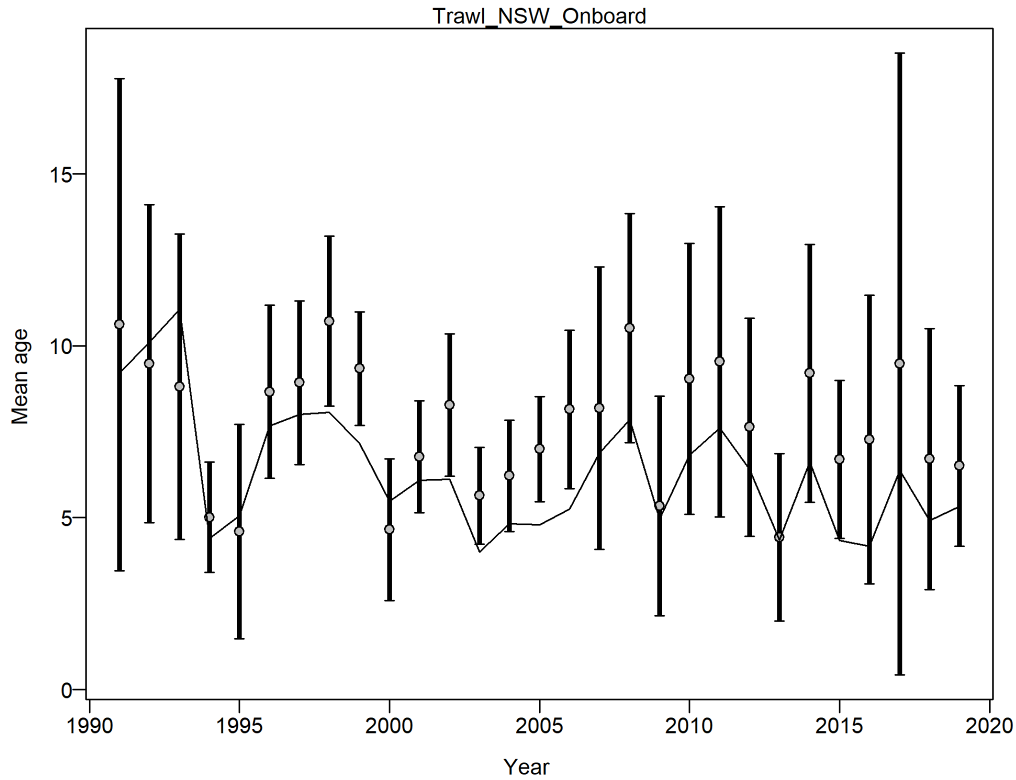


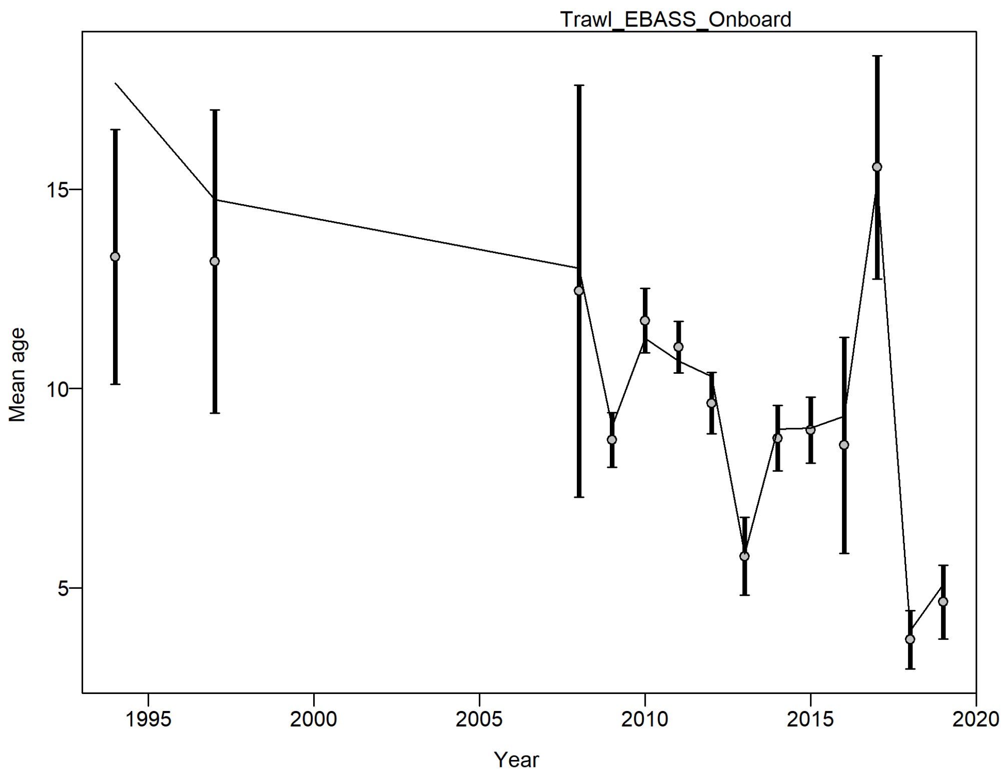

**Apx Figure A.17 Redfish NSW onboard age composition fits.**




**Apx Figure A.18 Redfish EBASS onboard age composition fits.**



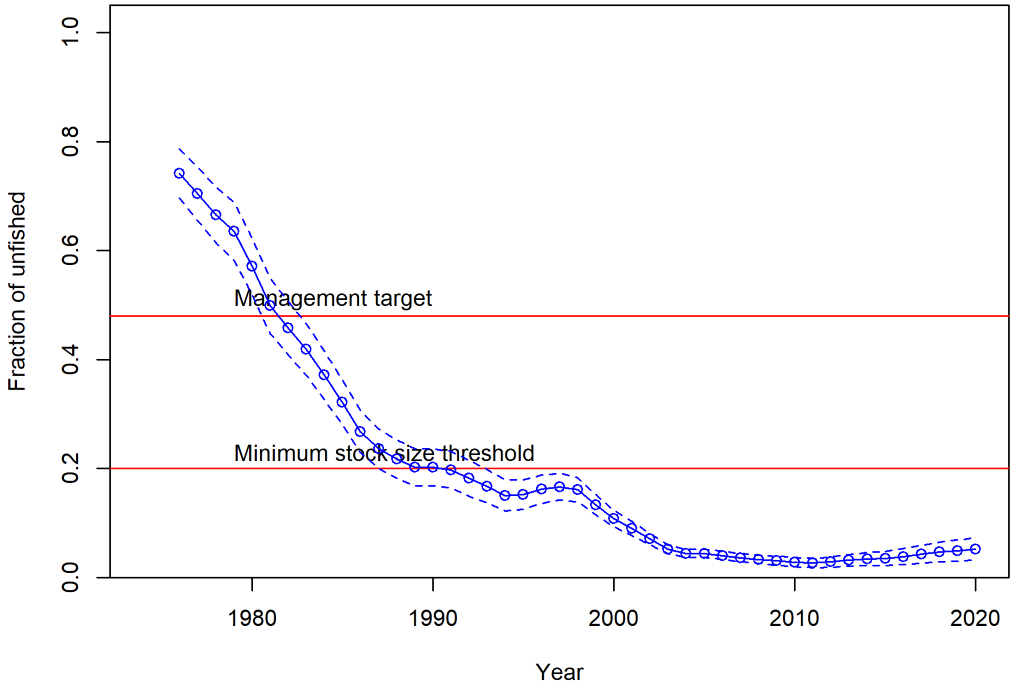

**Apx Figure A.19 Redfish NSW conditional age at length fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data.**



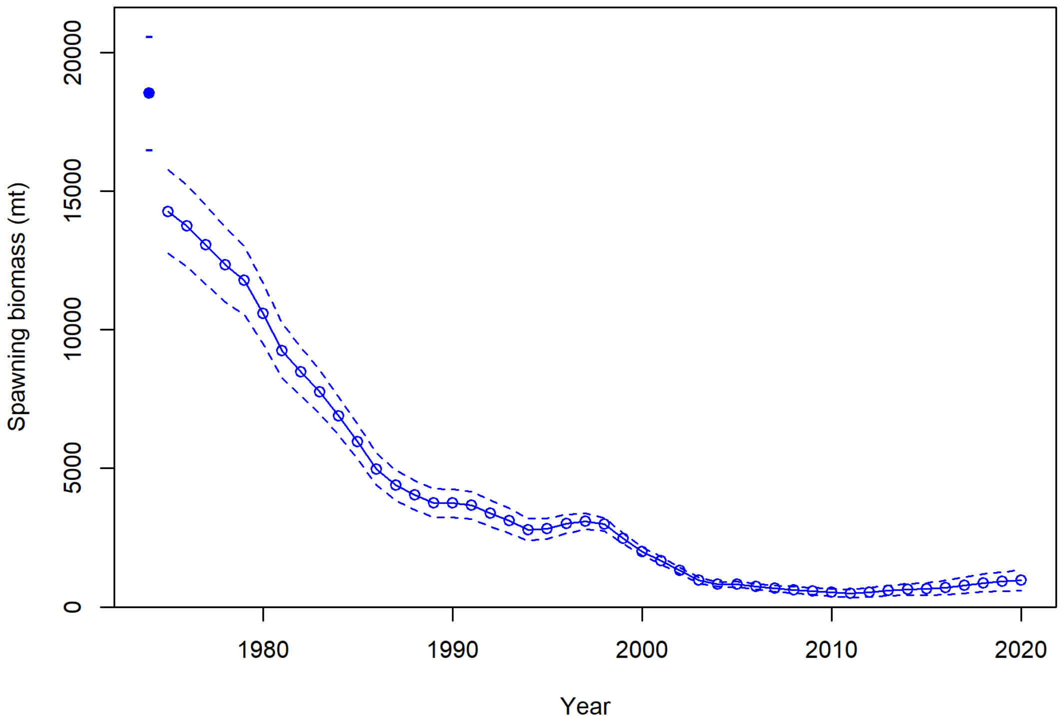

**Apx Figure A.20 Redfish EBASS conditional age at length fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data.**

# Appendix B

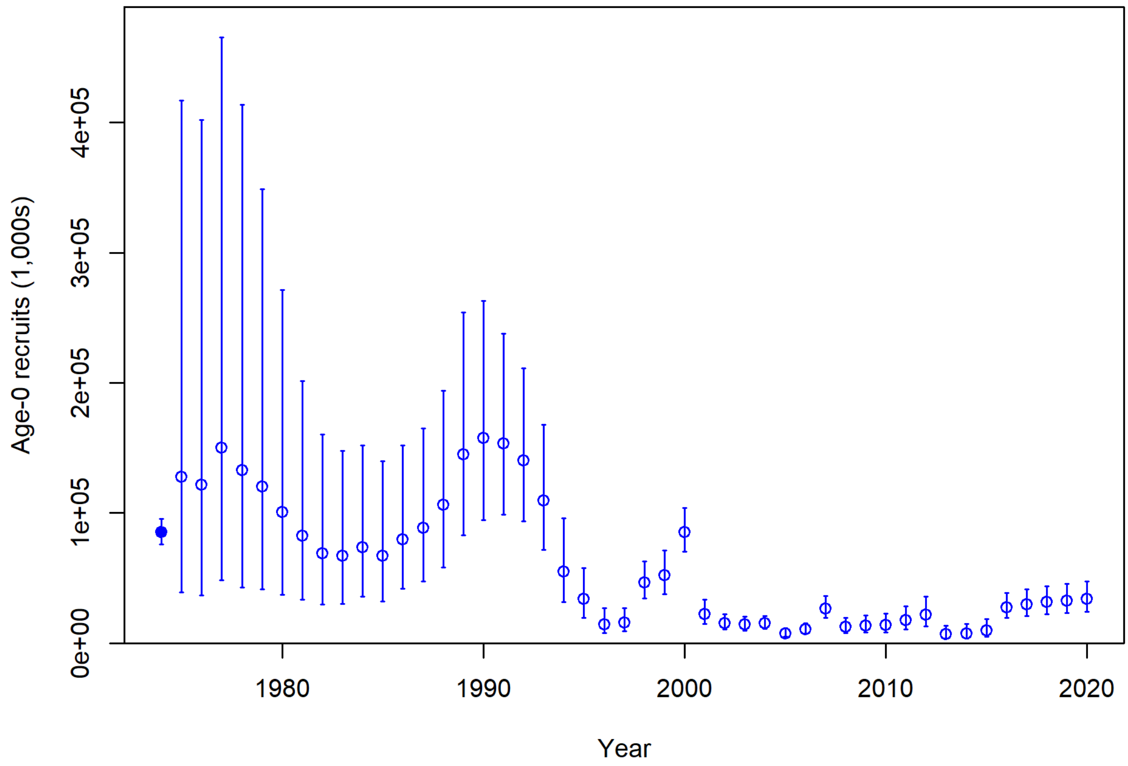
## B.1 Extra retention time block model diagnostics



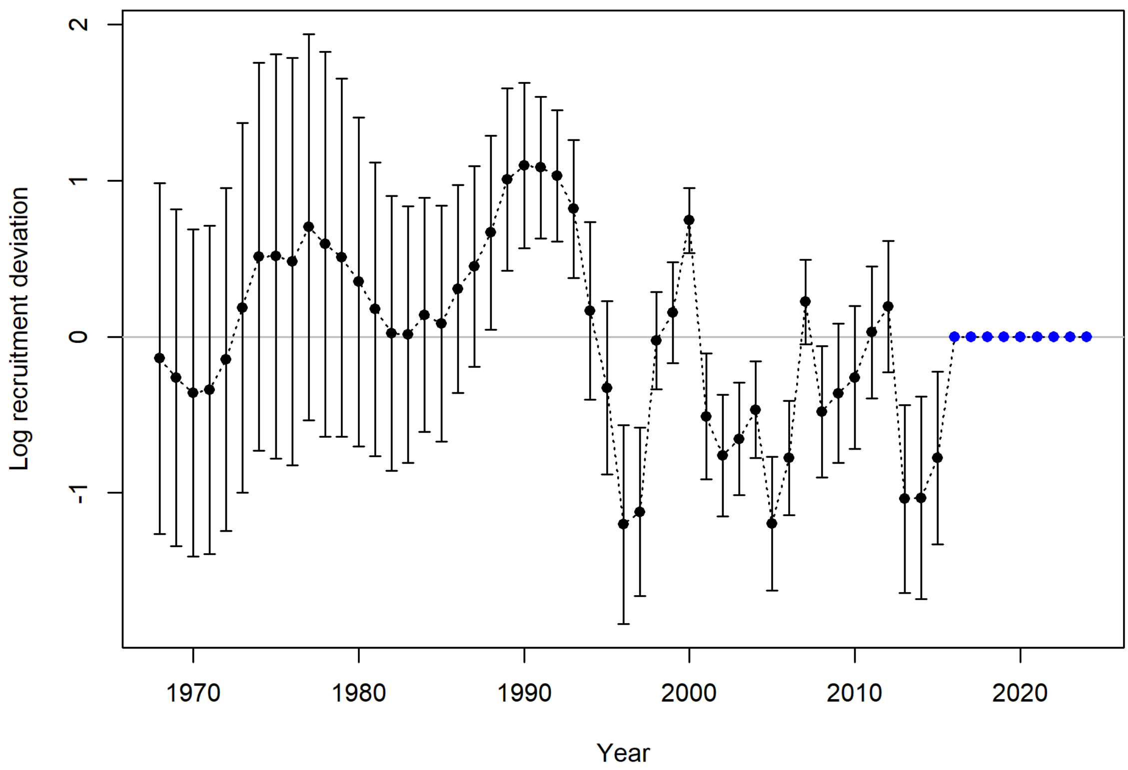

**Apx Figure B.1 The estimated time-series of relative spawning biomass for the 2020 extra retention sensitivity for Redfish.**




**Apx Figure B.2 The estimated time-series of absolute spawning biomass for the 2020 extra retention sensitivity for Redfish.**

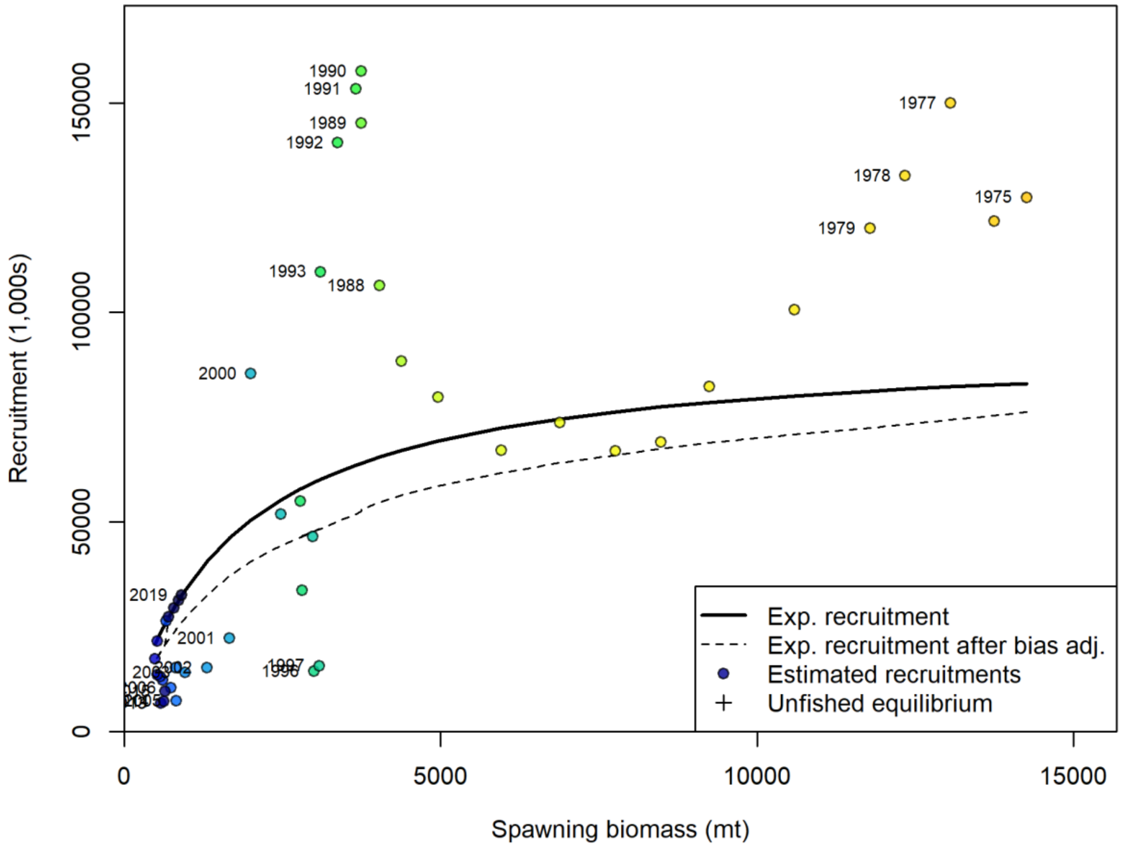



**Apx Figure B.3 Recruitment estimates with confidence intervals for the extra retention sensitivity model for Redfish.**

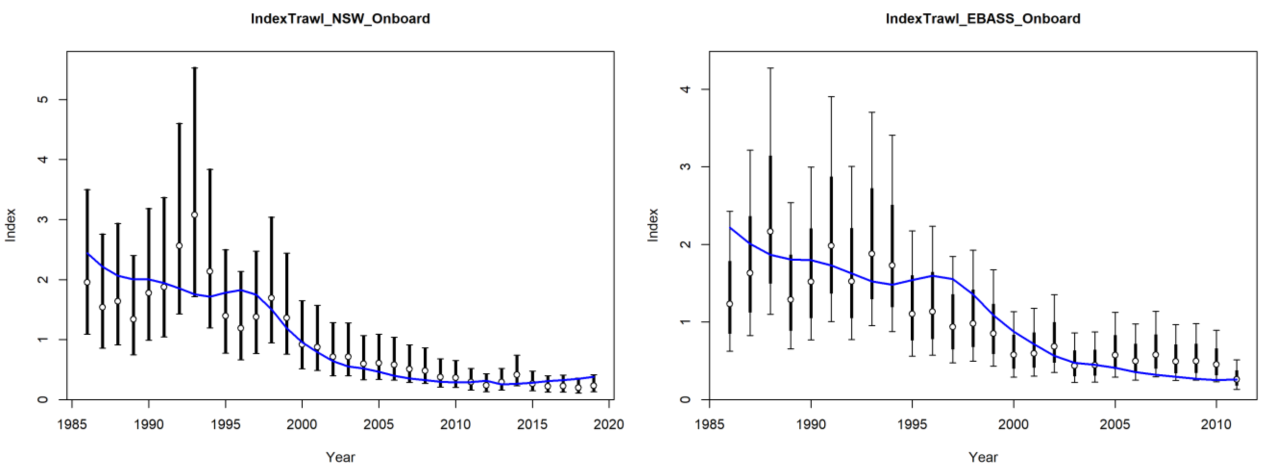



**Apx Figure B.4 Recruitment deviations with confidence intervals for the extra retention sensitivity model for Redfish.**

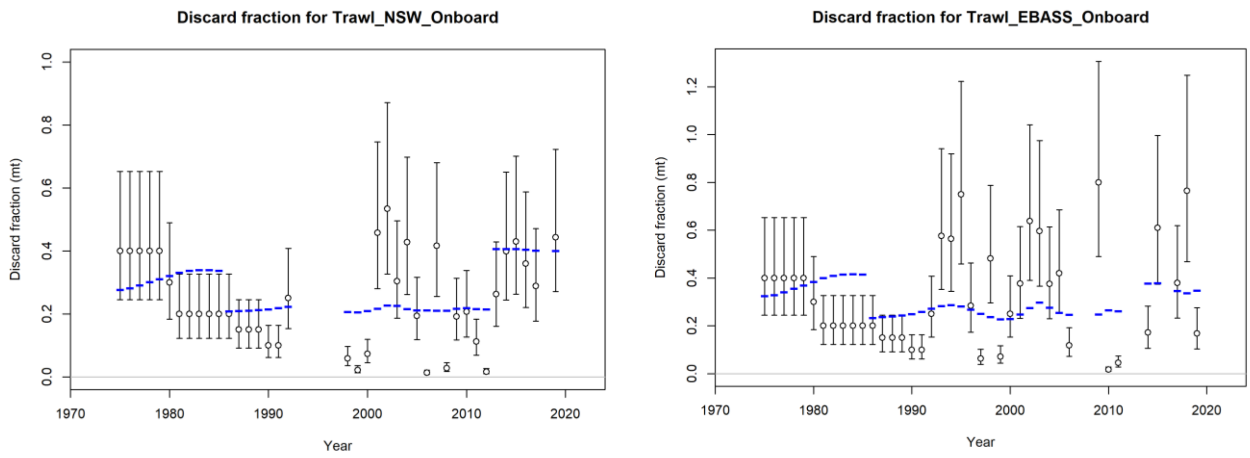
Apx Figure B.5 Phase plot of biomass vs SPR ratio for the extra retention sensitivity model for Redfish.



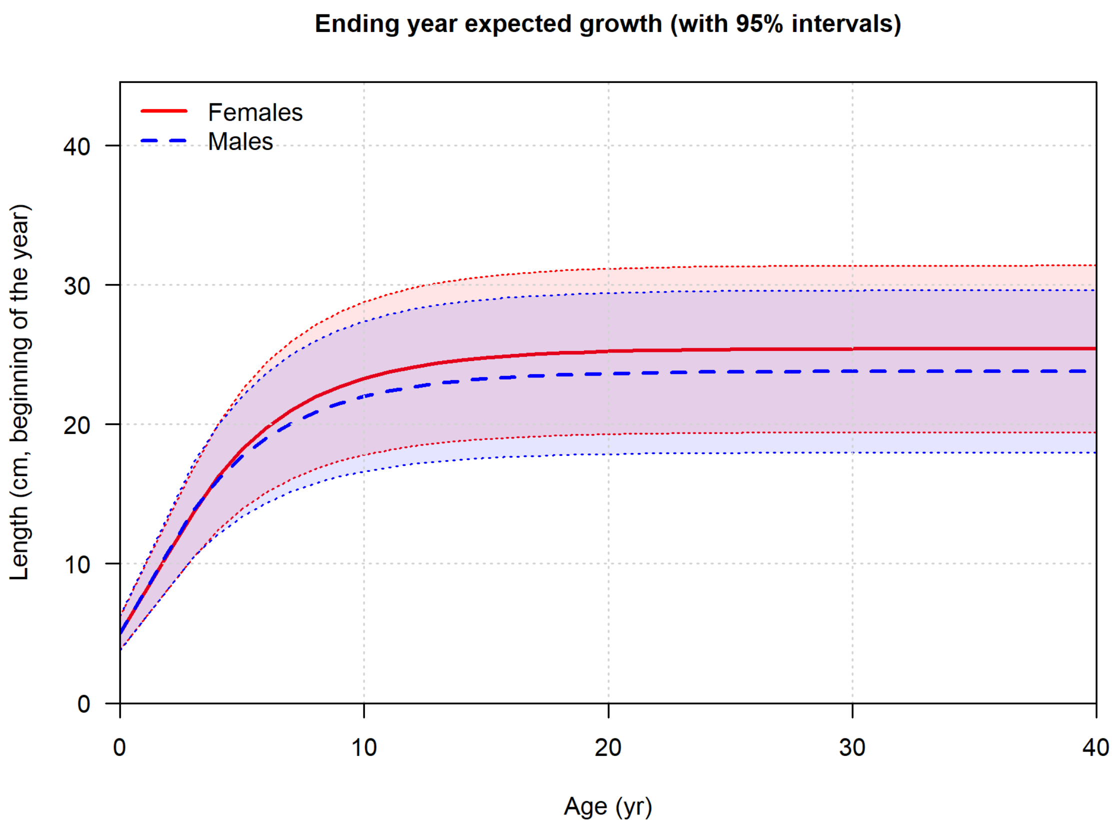

Apx Figure B.6 Stock recruitment curve for the extra retention sensitivity model for Redfish.



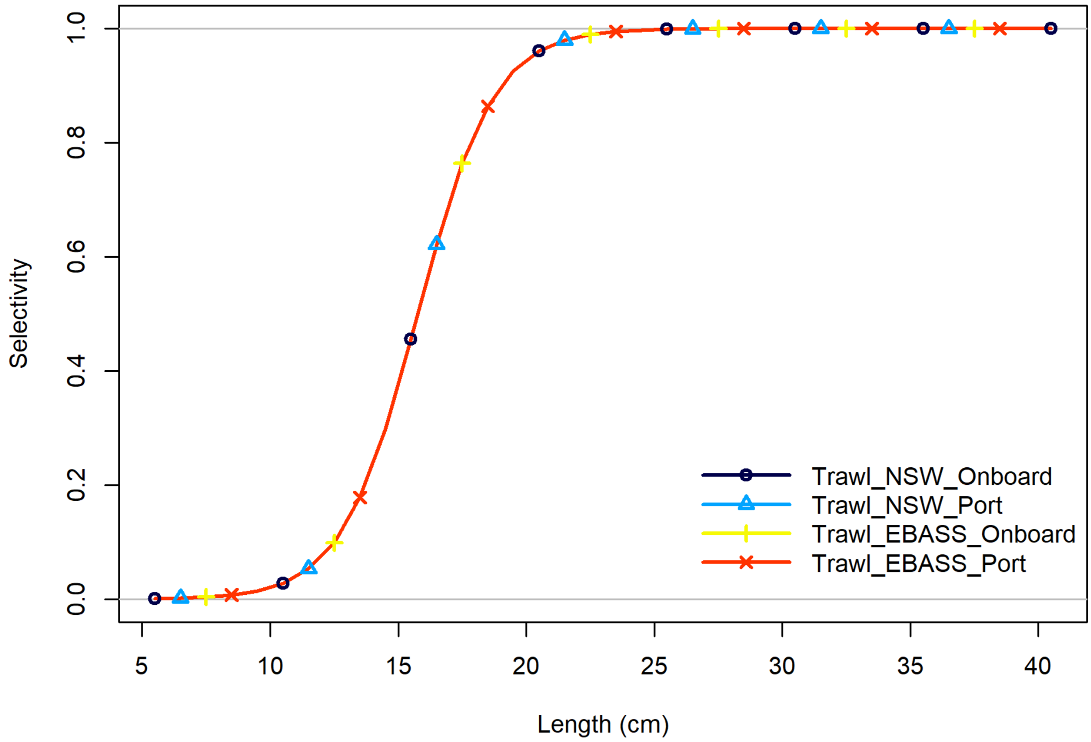
**Apx Figure B.7 Fits to trawl CPUE for the extra retention sensitivity model for Redfish, NSW is on the left and EBASS on the right.**



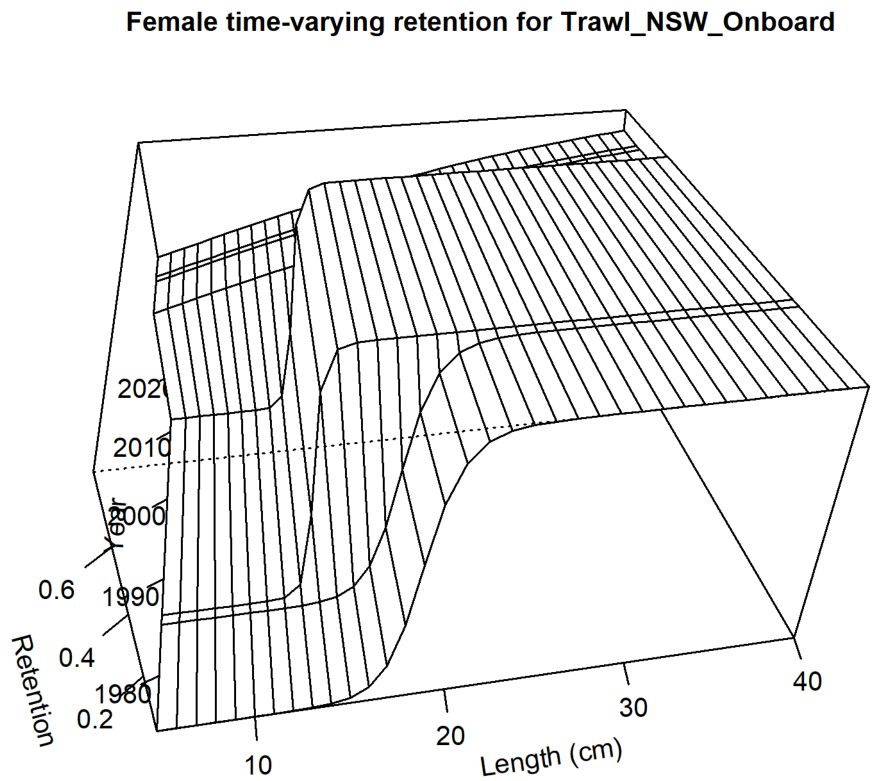

**Apx Figure B.8 Fits to trawl discards by region for the extra retention sensitivity model for Redfish.**

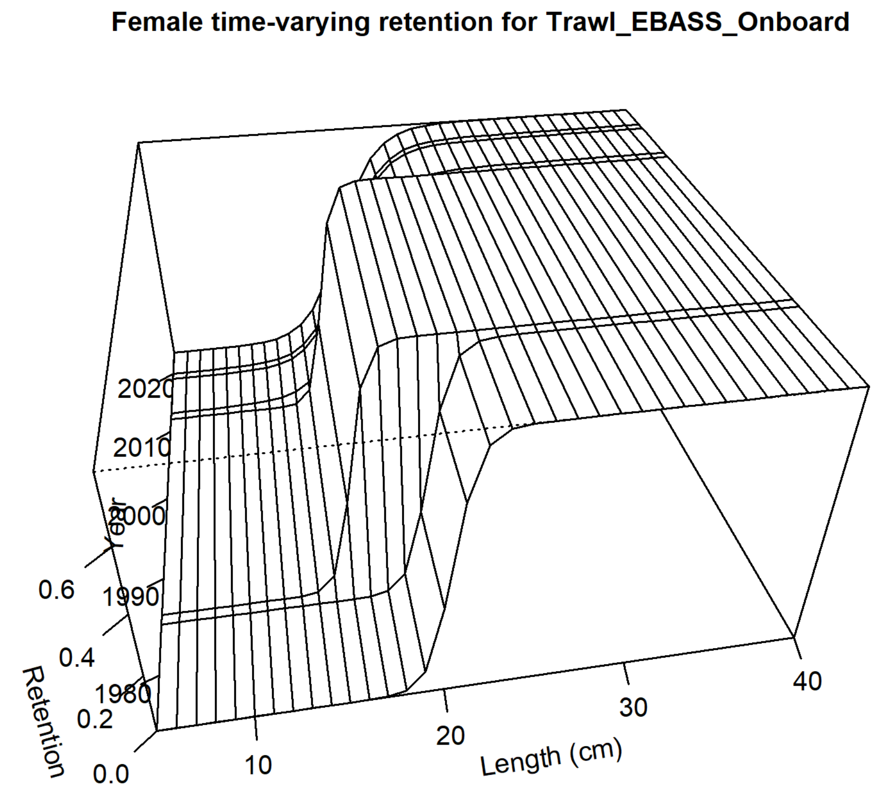



**Apx Figure B.9 The model estimated growth curves for the extra retention sensitivity model for Redfish.**

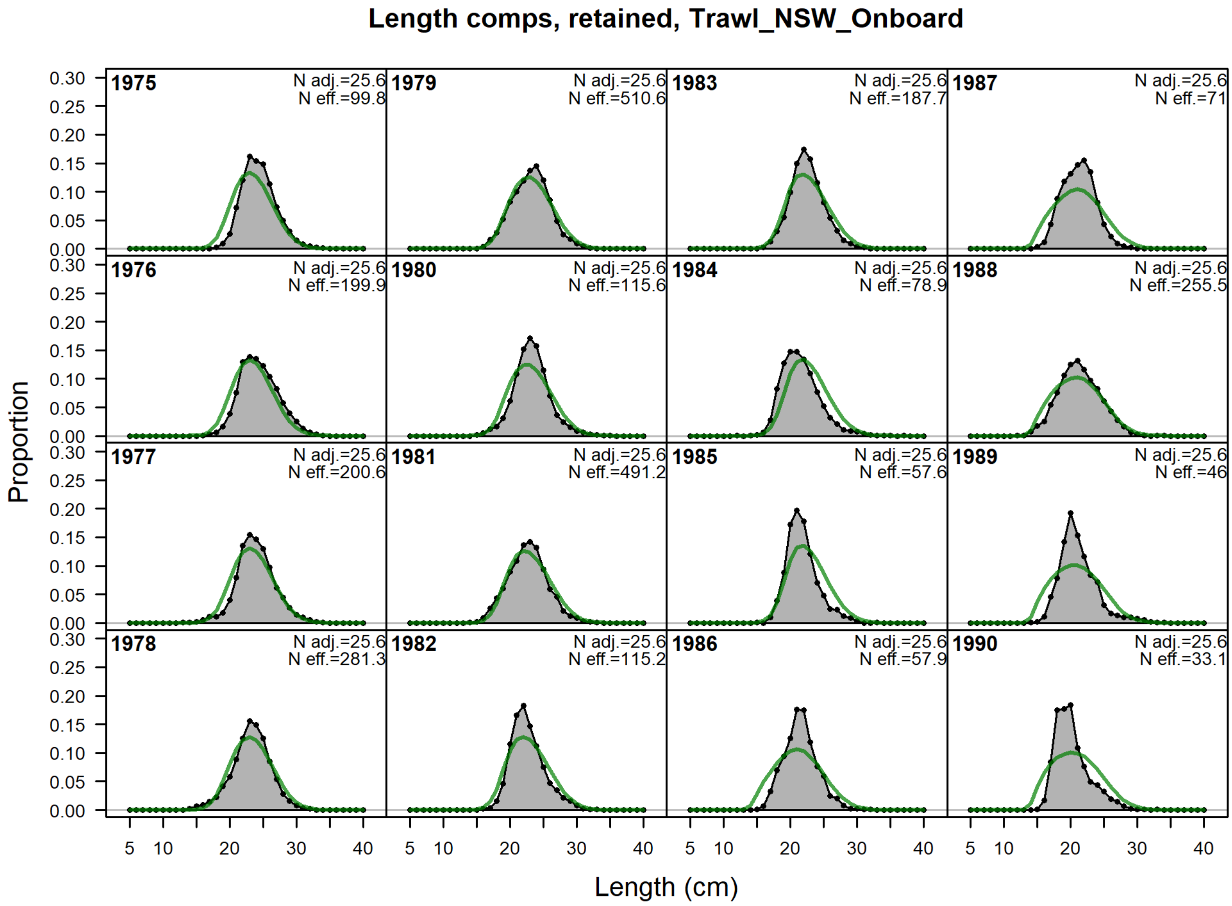


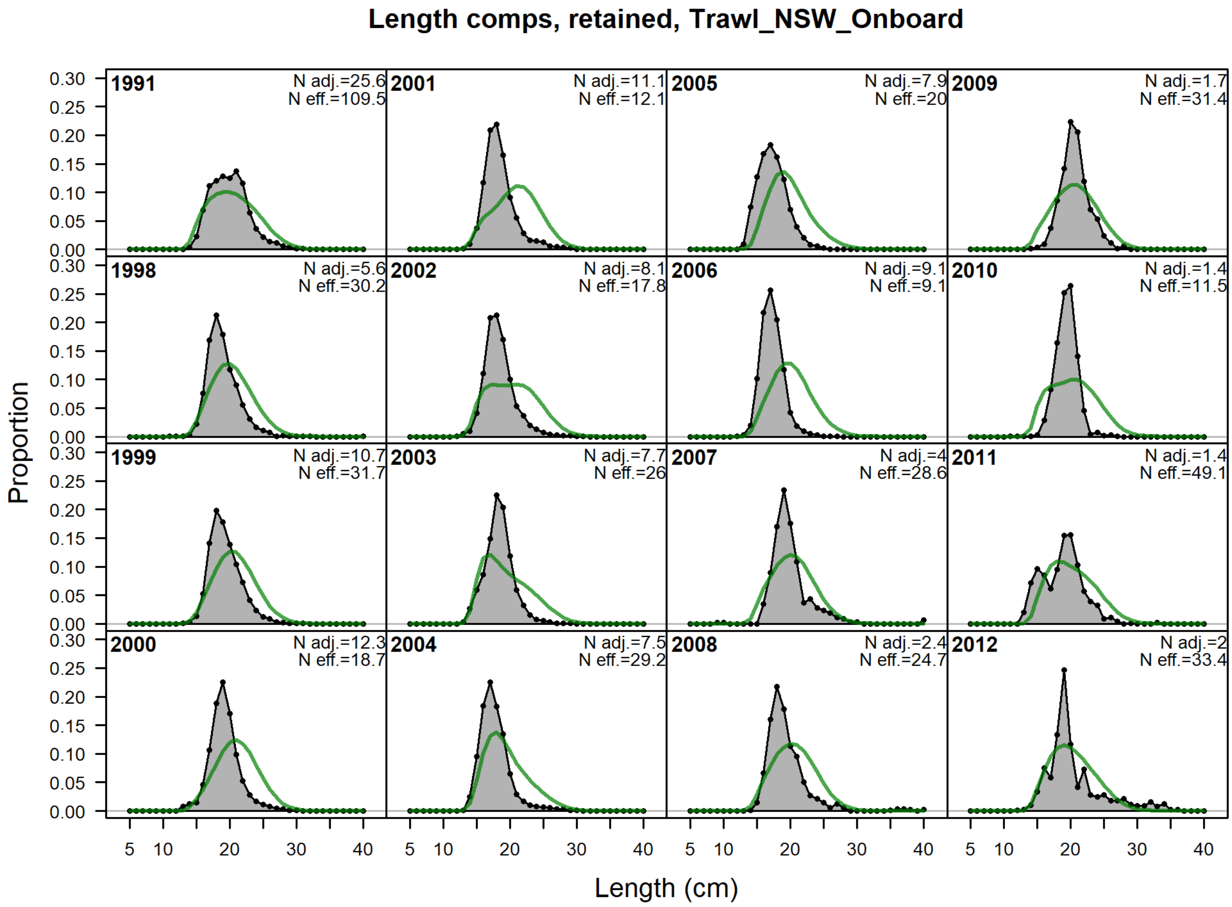

**Apx Figure B.10 Estimated selectivity curves for the extra retention sensitivity model for Redfish.**

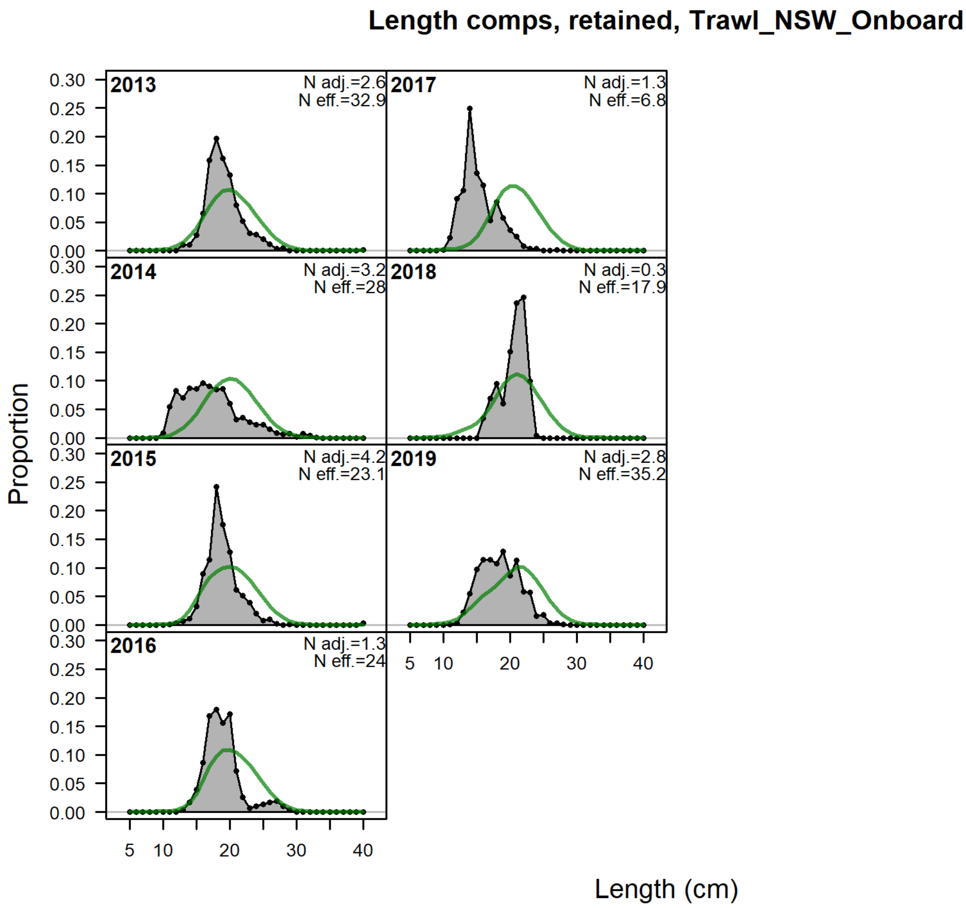



**Apx Figure B.11 The estimated retention functions for each region for the extra retention sensitivity model for Redfish.**

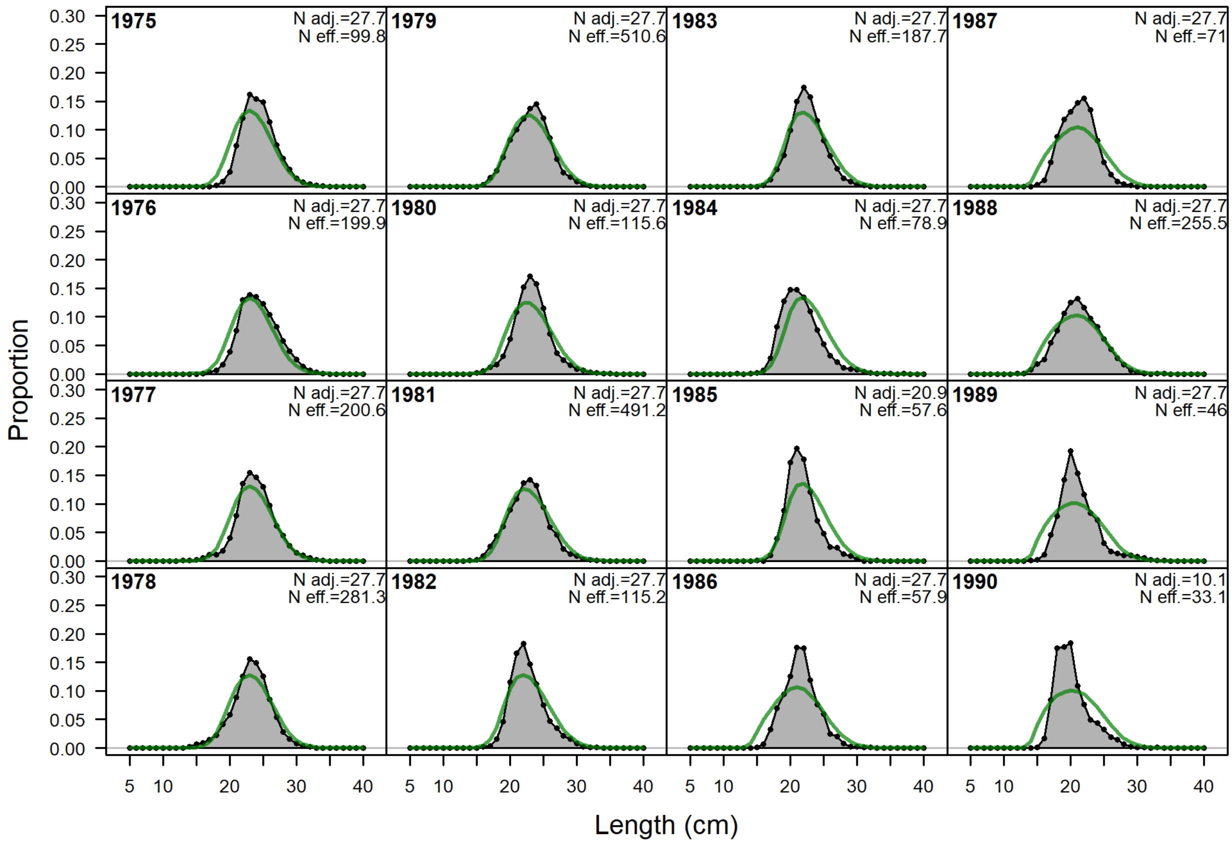

Length comps, retained, Trawl_NSW_Onboard
Proportion
Length (cm)
1975
N adj.=25.6
N eff.=99.8
1979
N adj.=25.6
N eff.=510.6
1983
N adj.=25.6
N eff.=187.7
1987
N adj.=25.6
N eff.=71
1976
N adj.=25.6
N eff.=199.9
1980
N adj.=25.6
N eff.=115.6
1984
N adj.=25.6
N eff.=78.9
1988
N adj.=25.6
N eff.=255.5
1977
N adj.=25.6
N eff.=200.6
1981
N adj.=25.6
N eff.=491.2
1985
N adj.=25.6
N eff.=57.6
1989
N adj.=25.6
N eff.=46
1978
N adj.=25.6
N eff.=281.3
1982
N adj.=25.6
N eff.=115.2
1986
N adj.=25.6
N eff.=57.9
1990
N adj.=25.6
N eff.=33.1


Length comps, retained, Trawl_NSW_Onboard
Proportion
Length (cm)
1991
N adj.=25.6
N eff.=109.5
2001
N adj.=11.1
N eff.=12.1
2005
N adj.=7.9
N eff.=20
2009
N adj.=1.7
N eff.=31.4
1998
N adj.=5.6
N eff.=30.2
2002
N adj.=8.1
N eff.=17.8
2006
N adj.=9.1
N eff.=9.1
2010
N adj.=1.4
N eff.=11.5
1999
N adj.=10.7
N eff.=31.7
2003
N adj.=7.7
N eff.=26
2007
N adj.=4
N eff.=28.6
2011
N adj.=1.4
N eff.=49.1
2000
N adj.=12.3
N eff.=18.7
2004
N adj.=7.5
N eff.=29.2
2008
N adj.=2.4
N eff.=24.7
2012
N adj.=2
N eff.=33.4

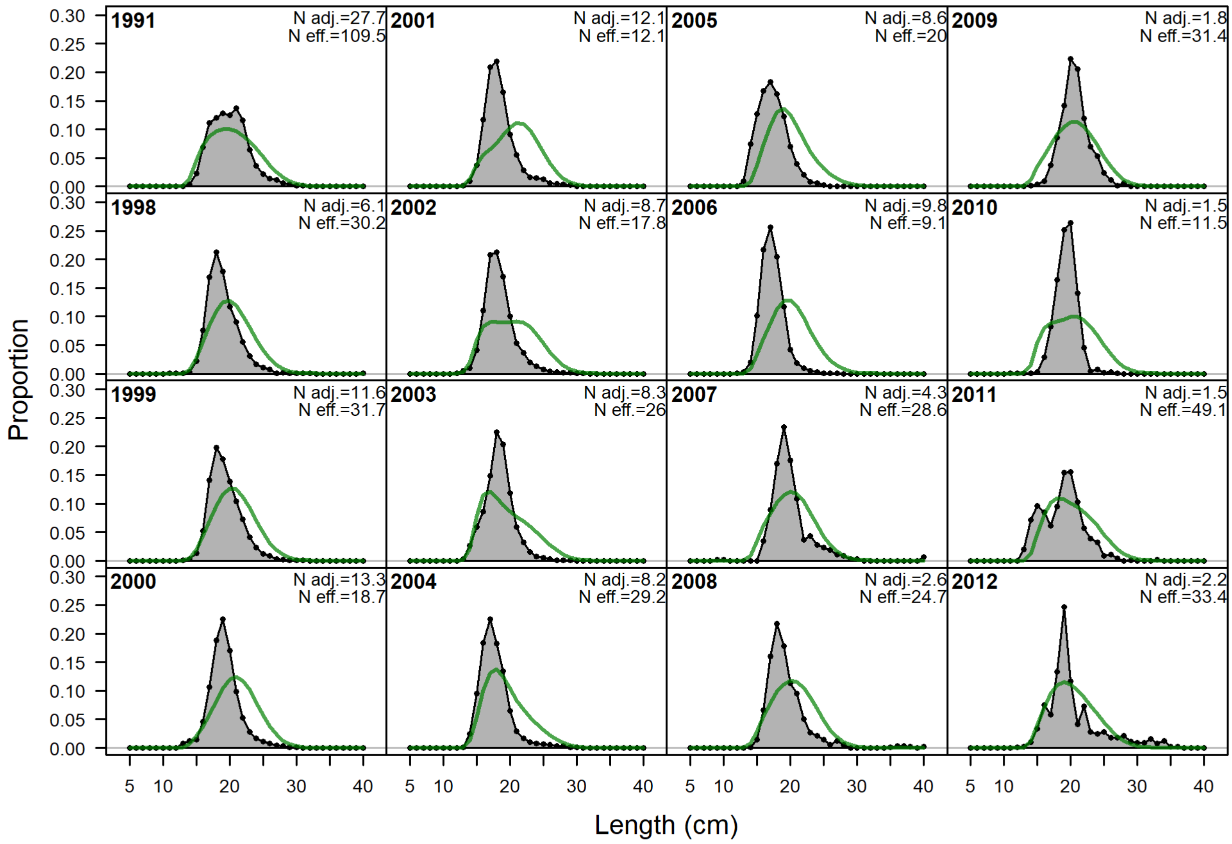


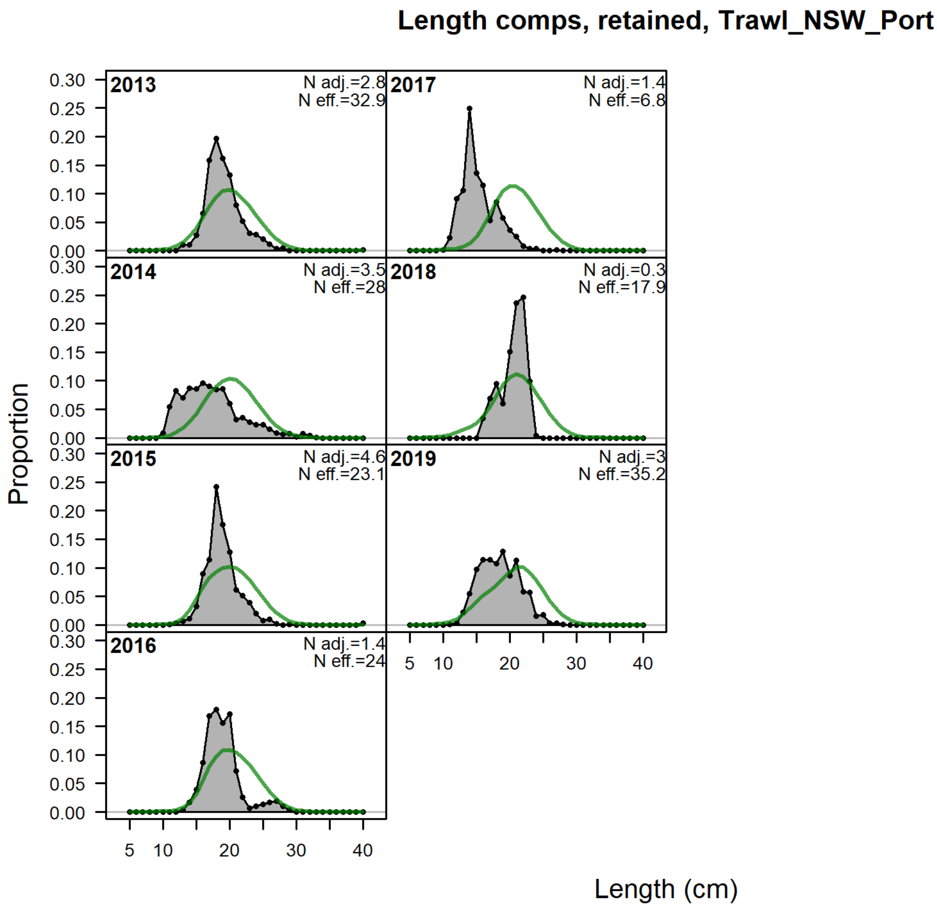

**Apx Figure B.12 Redfish length composition fits: onboard NSW trawl retained for the extra retention sensitivity model for Redfish.**

## Length comps, retained, Trawl_NSW_Port

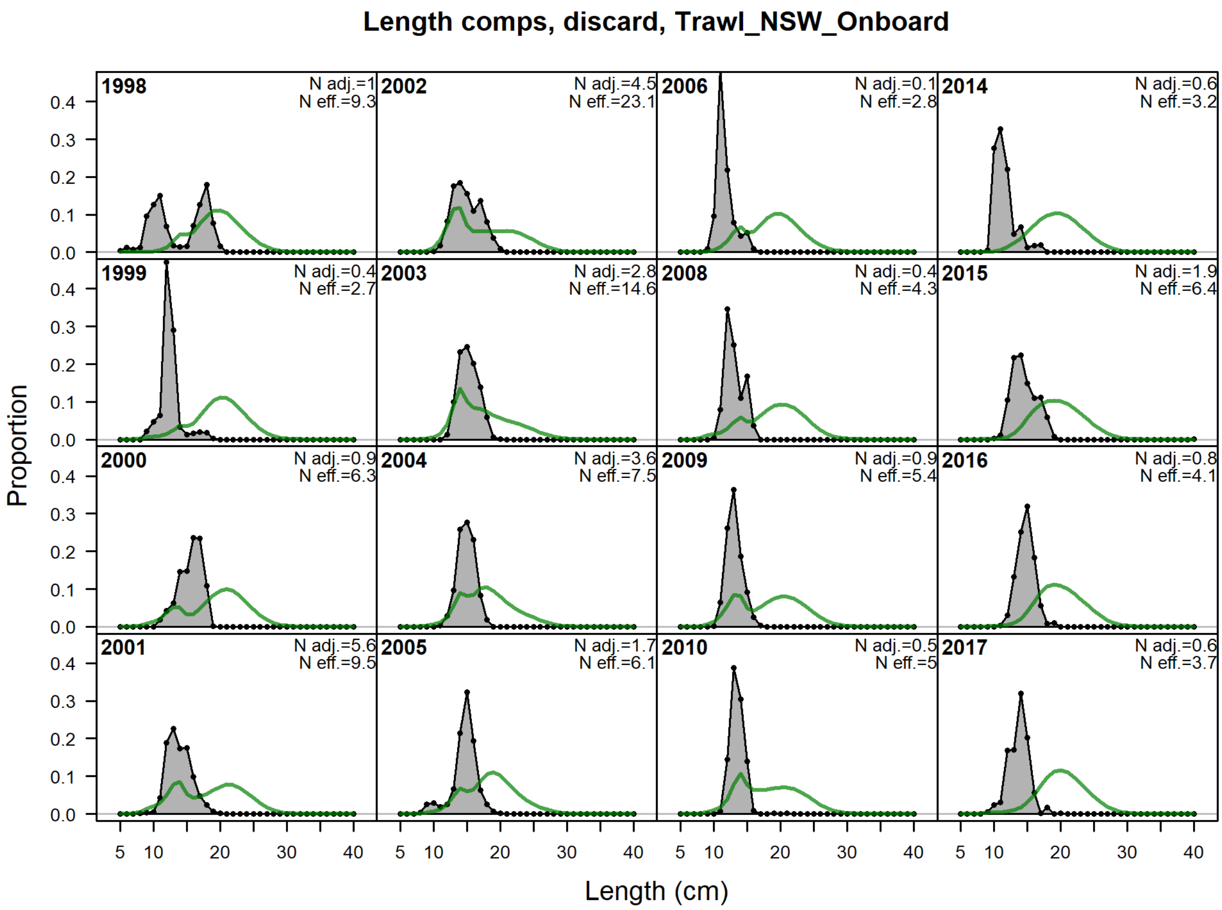


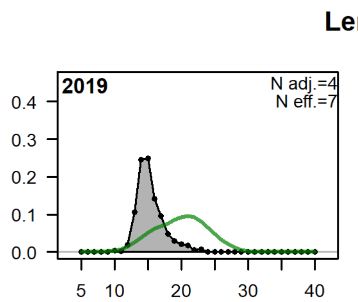

## Length comps, retained, Trawl_NSW_Port



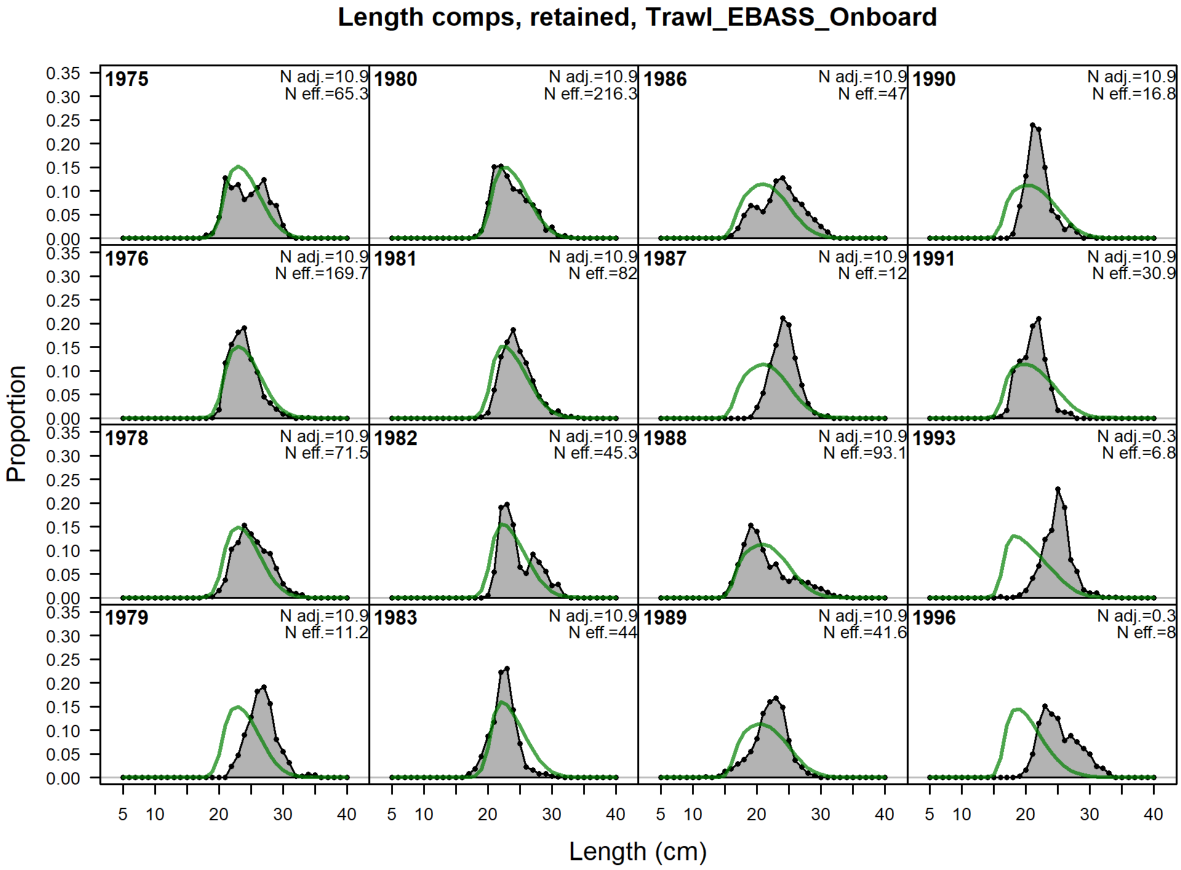


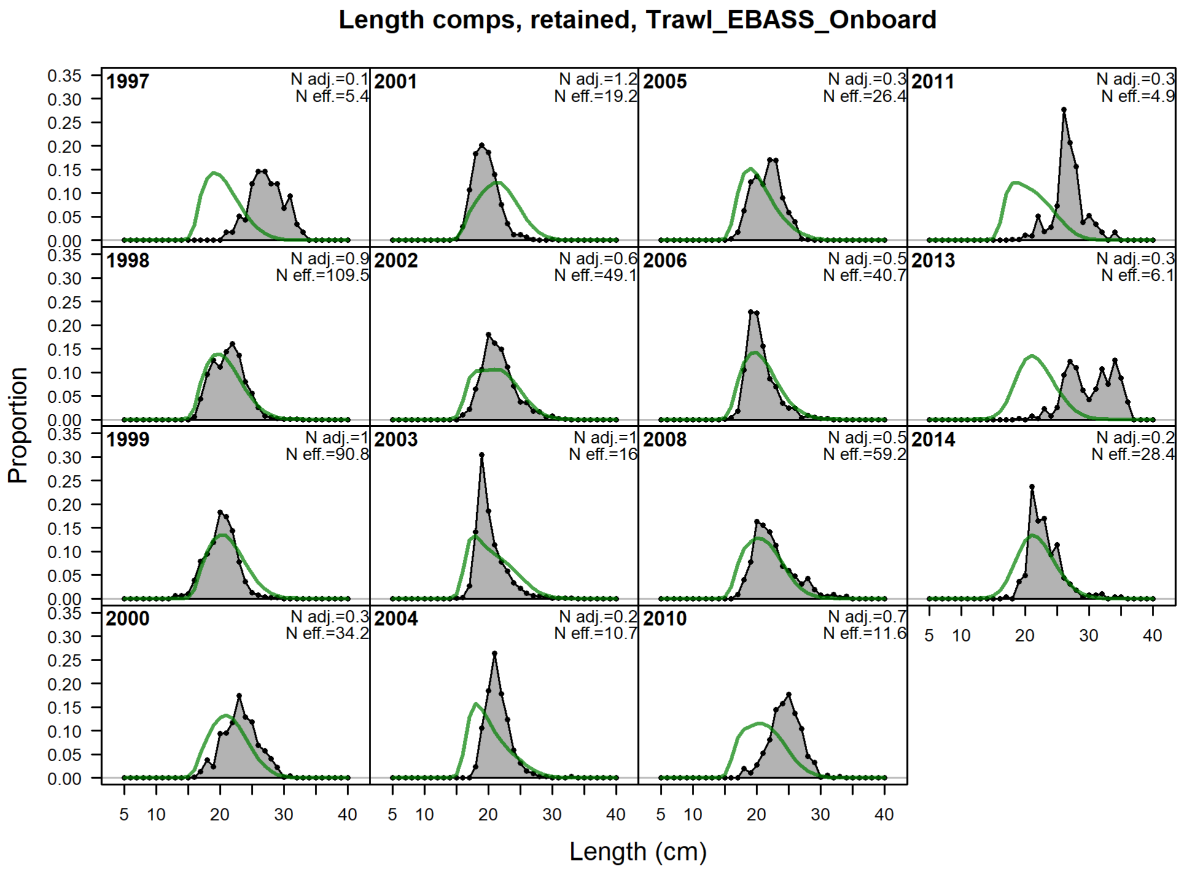

**Apx Figure B.13 Redfish length composition fits: NSW port trawl for the extra retention sensitivity model for Redfish.**



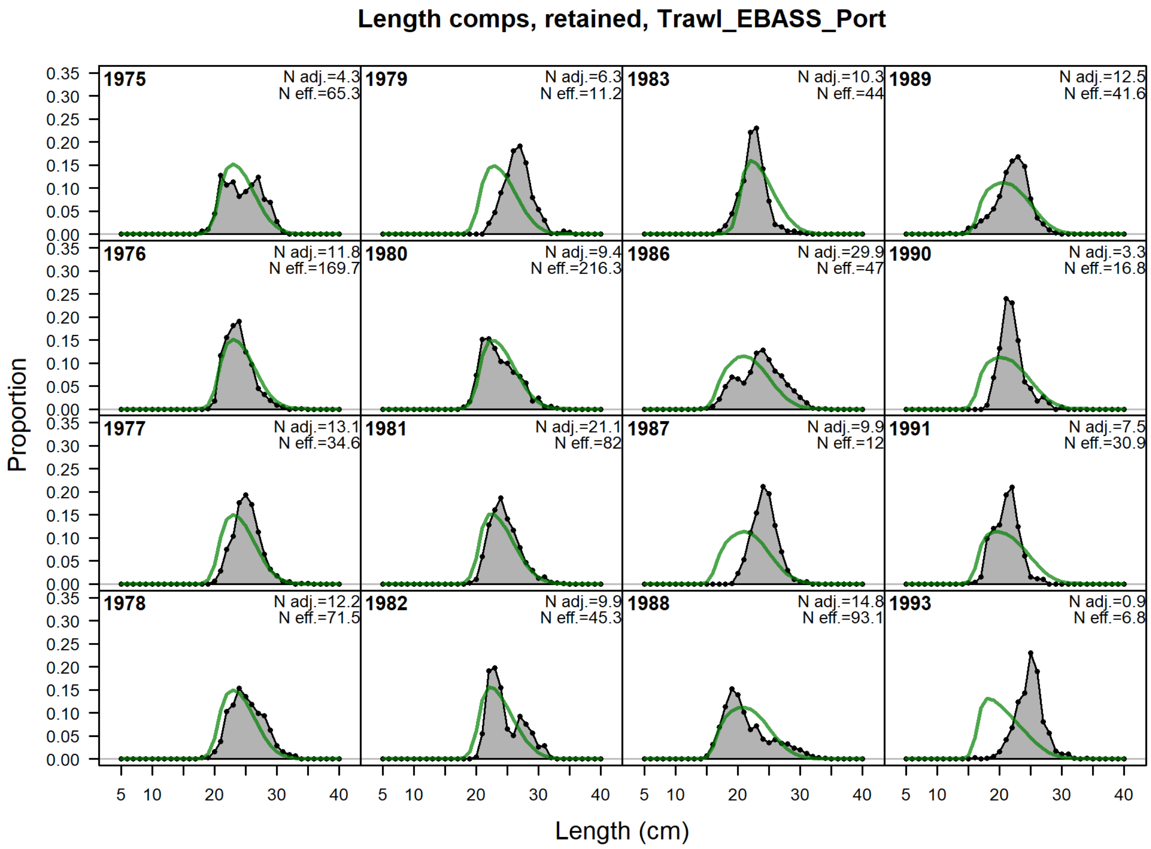



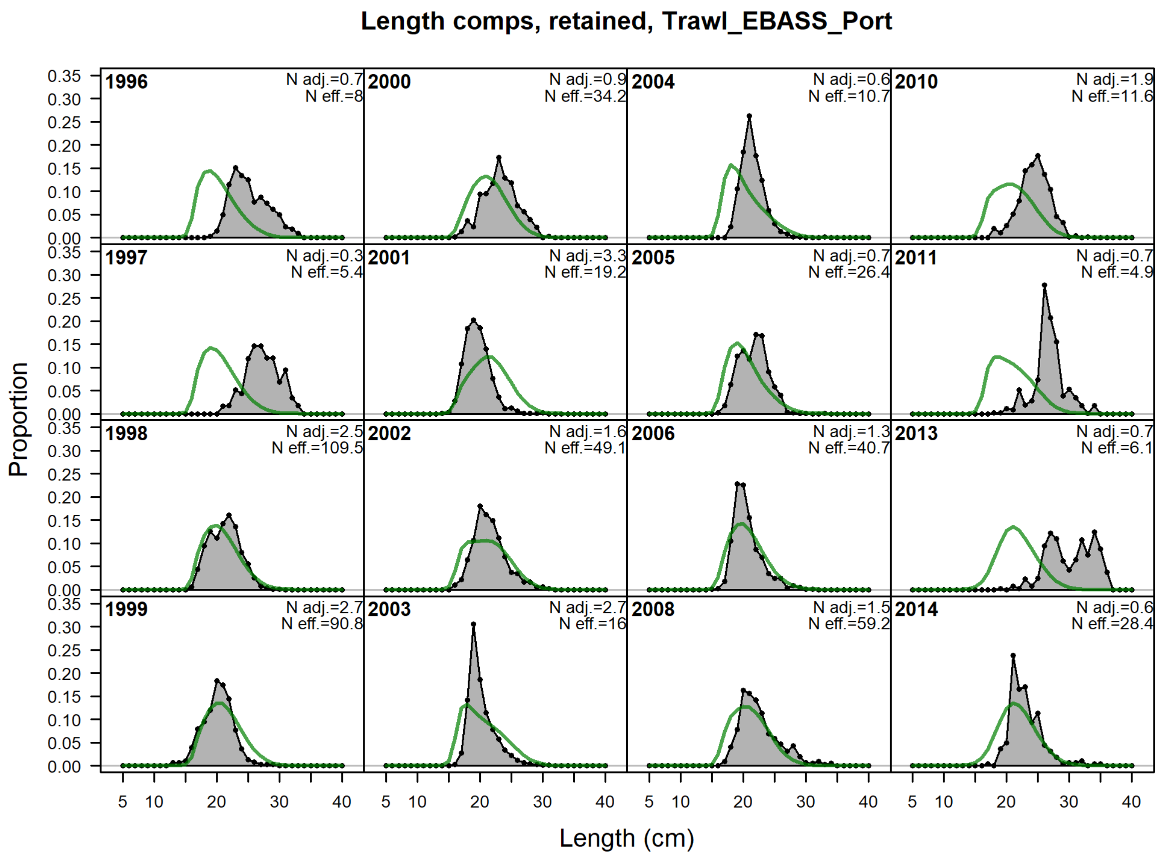

**Apx Figure B.14 Redfish length composition fits: onboard NSW trawl discard for the extra retention sensitivity model for Redfish.**



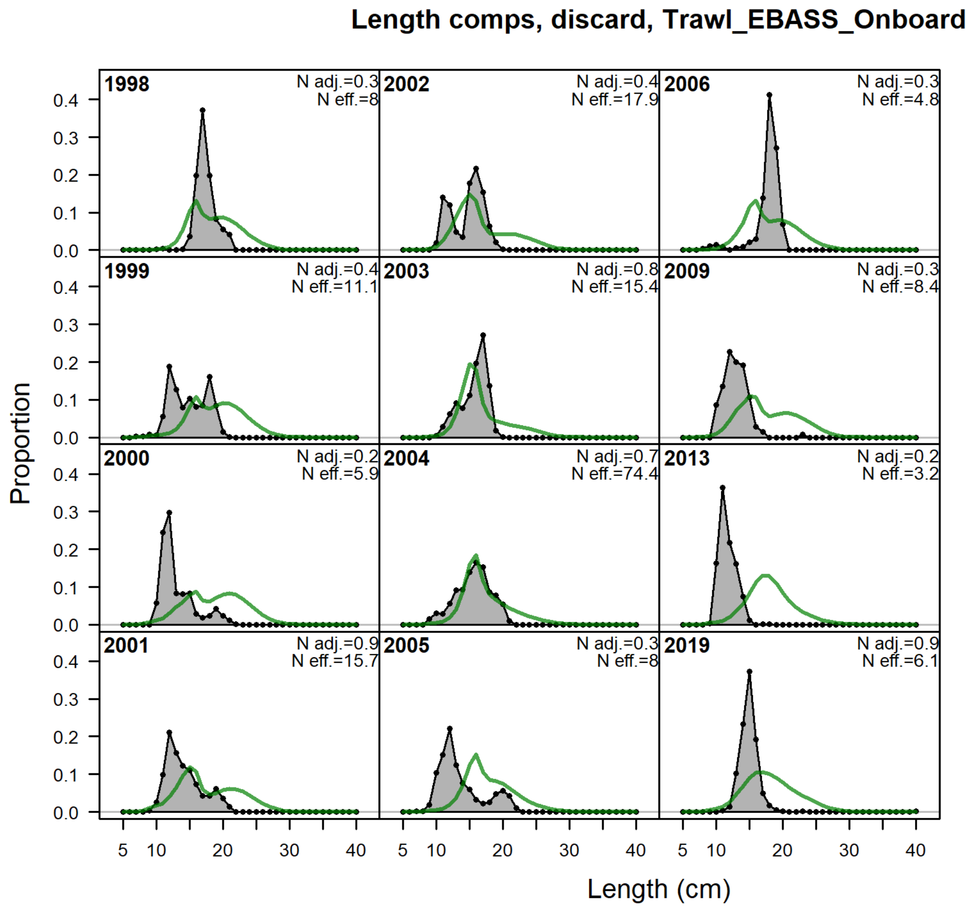




**Apx Figure B.15 Redfish length composition fits: onboard EBASS trawl retained for the extra retention sensitivity model for Redfish.**

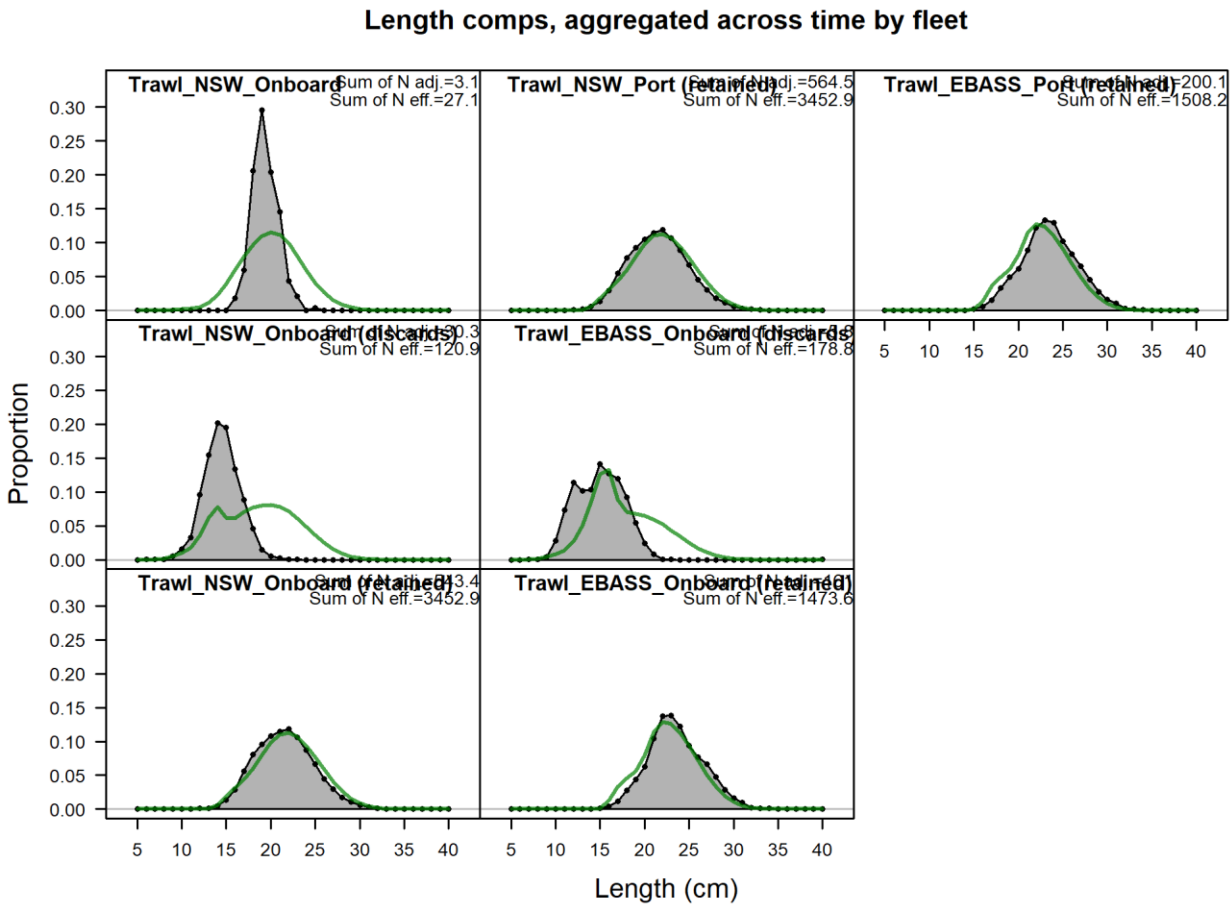


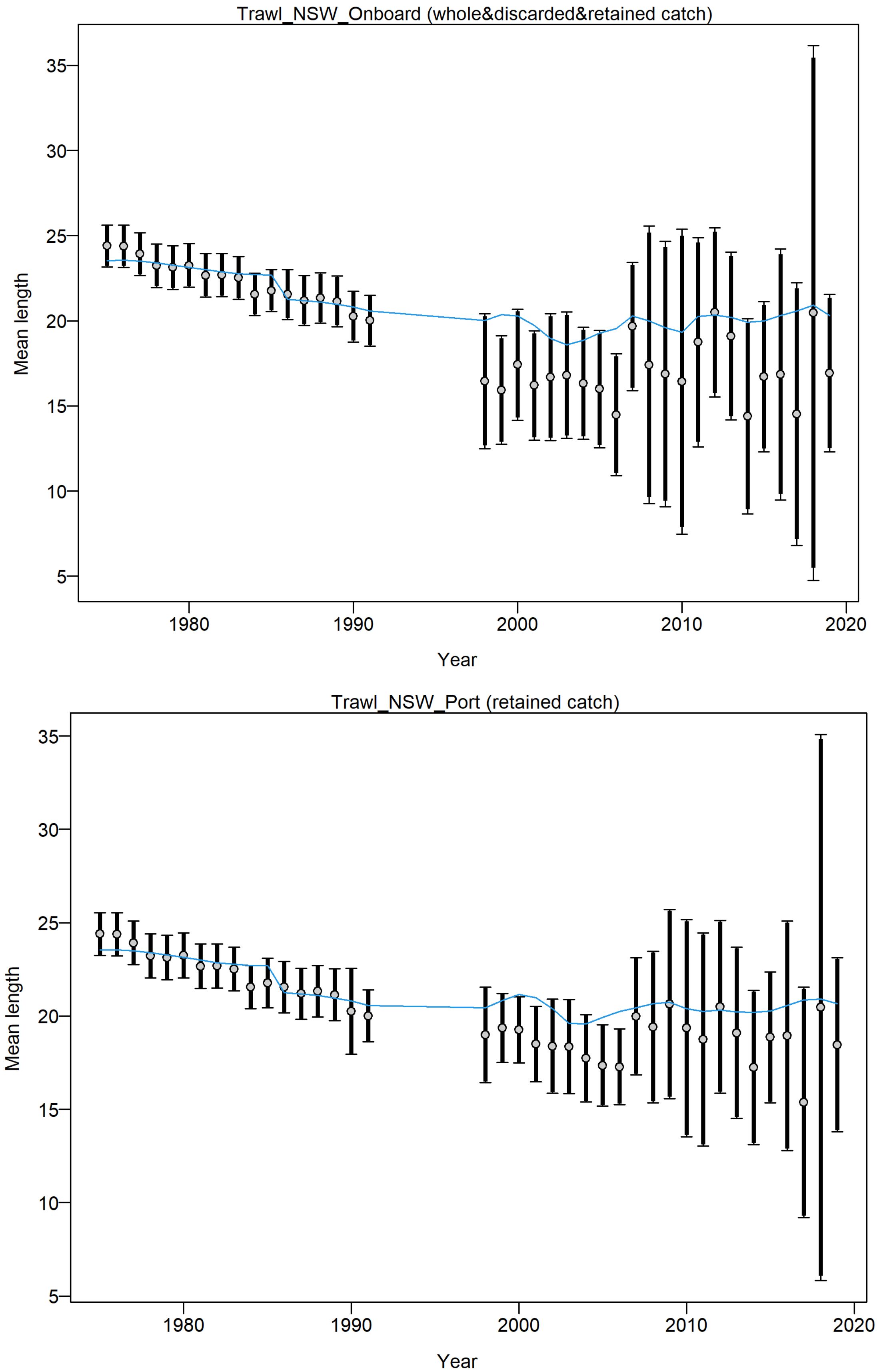

**Apx Figure B.16 Redfish length composition fits: EBASS port trawl for the extra retention sensitivity model for Redfish.**



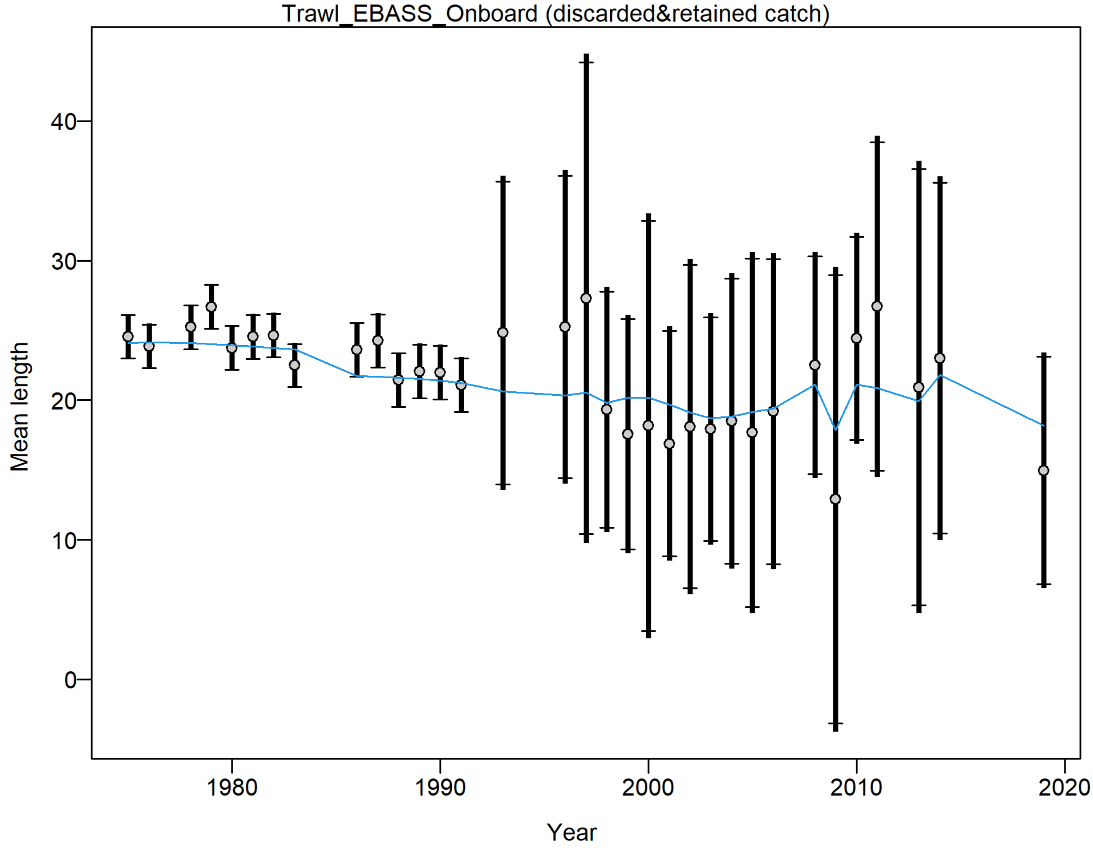

**Apx Figure B.17 Redfish length composition fits: onboard EBASS trawl discard for the extra retention sensitivity model for Redfish.**

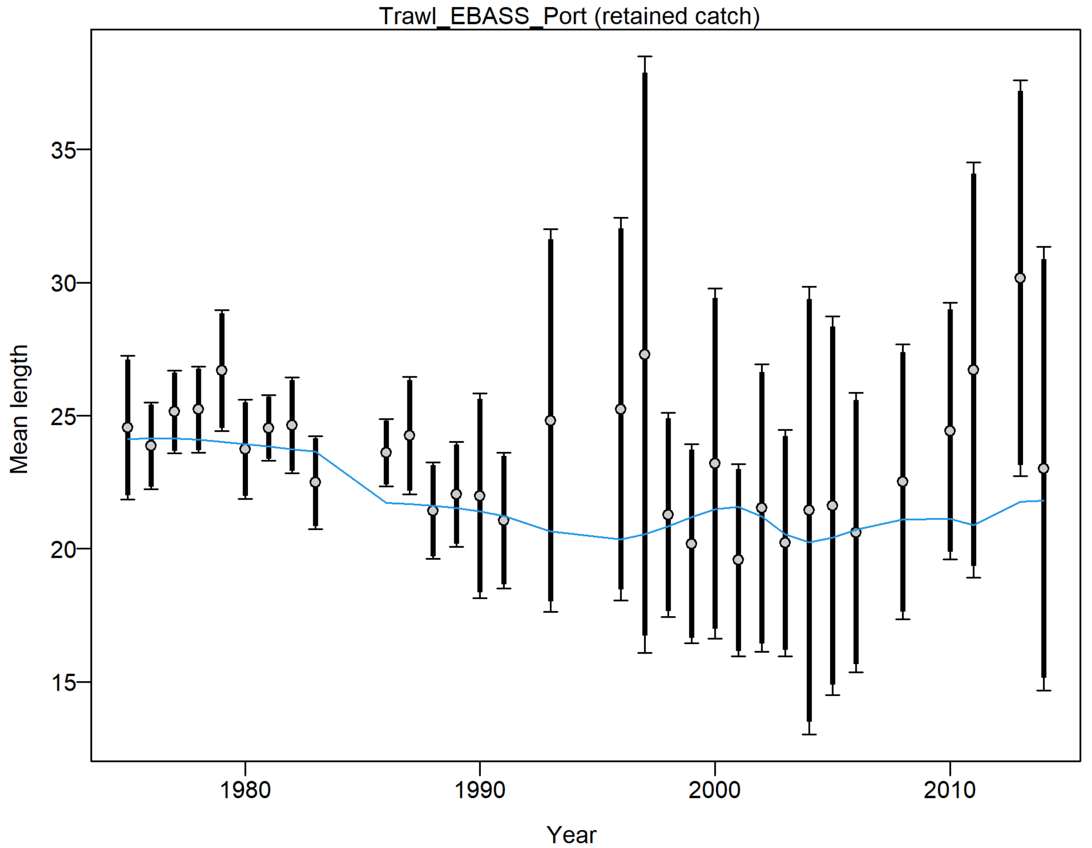



**Apx Figure B.18 Redfish length composition fit aggregated across years for the extra retention sensitivity model for Redfish.**

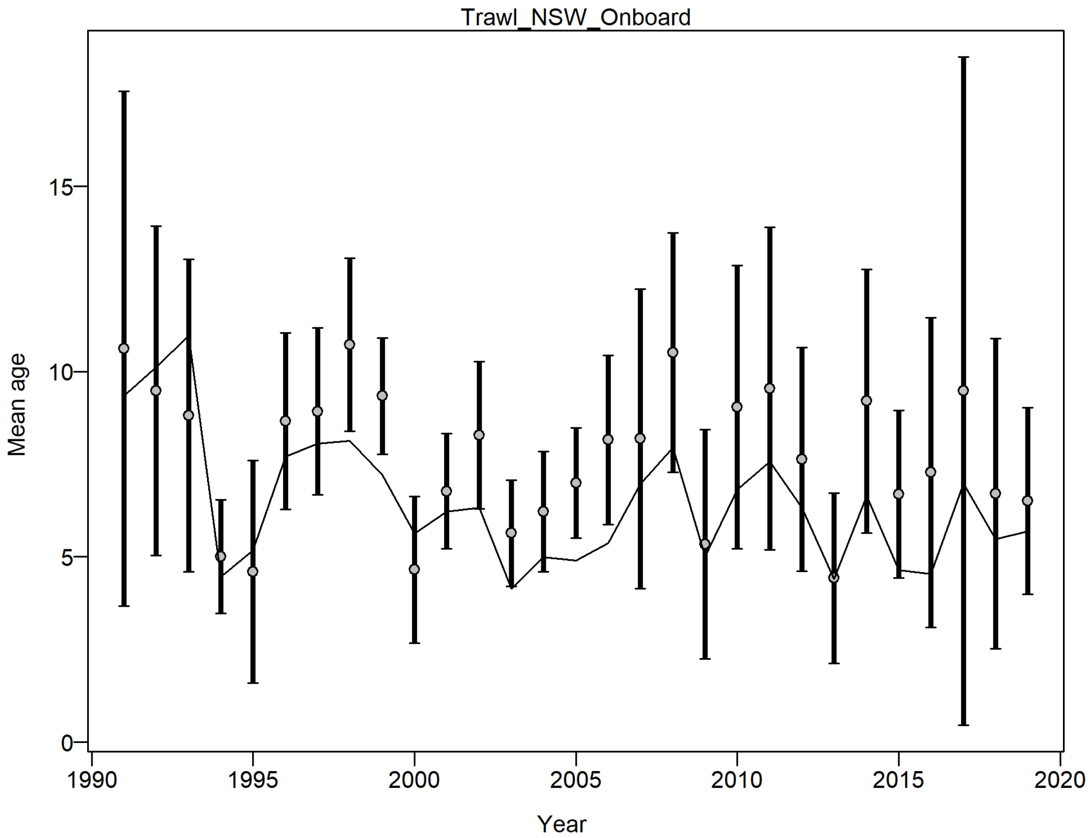


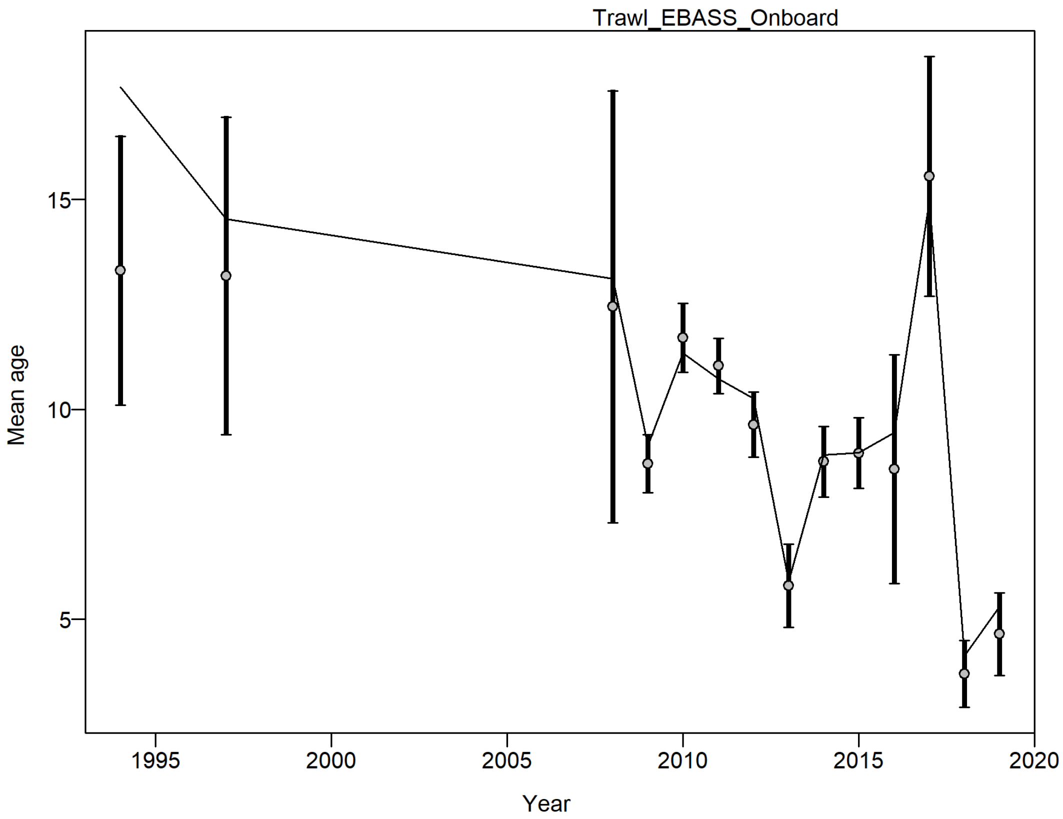

**Apx Figure B.19 Redfish NSW length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.**




**Apx Figure B.20 Redfish EBASS length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.**




**Apx Figure B.21 Redfish conditional age at length fit diagnostics from tuning for NSW and EBASS. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data.**

# References

Berger, A.M., Jones, M.L., Zhao, Y., Bence, J.R. 2012. Accounting for spatial population structure at scales relevant to life history improves stock assessment: the case for Lake Erie walleye *Sander vitreus*. Fish. Res. 115–116, 44–59.

Bessell-Browne, P. and Tuck, G.N. 2020. Redfish (*Centroberyx affinis*) stock assessment based on data up to 2019 – development of a preliminary base case. Technical paper presented to the SERAG, 19-21 October 2020, Hobart, Australia.

Chesson, J. 1995. Redfish, 1993, Stock Assessment Report, South East Fishery Assessment Group, Australian Fisheries Management Authority, Canberra.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

Haddon, M. 2014. Length at Age for Redfish (*Centroberyx affinis*). CSIRO, Oceans and Atmosphere, Hobart, Australia. 34p.

Hilborn, R., Maunder, M., Parma, A., Ernst, B., Payne, J. and Starr, P. 2000. Coleraine – A generalized age structured stock assessment model. http://www.fish.washington.edu/research/coleraine/

Houston, T.W. 1955. The New South Wales trawl fishery: Review of past course and examination of present condition. Australian Journal of Marine and Freshwater Research 6:165-208

Hurtado-Ferro, F., Punt, A.E., Hill, K.T. 2014. Use of multiple selectivity patterns as a proxy for spatial structure. Fish. Res. 158, 102–115.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. and Grieve, C. 1993. Australian Fisheries Resources. Australian Bureau of Resource Sciences. Canberra

Klaer, N. 2005. Examination of the effect of changes in mesh selectivity on the stock status of redfish (*Centroberyx affinis*). In Tuck, G.N. (ed.) 2006. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 292 p.

Liggins, G.W., Bradley, M.J., Kennelly, S.J., 1997. Detection of bias in observer-based estimates of retained and discarded catches from a multi species trawl fishery. Fisheries Research, 32: 133-147.

Methot, R.D. 2005 Technical Description of the Stock Synthesis II Assessment Program. NOAA Fisheries Service, Seattle. 54 pp

Methot, R.D. 2020. User manual for Stock Synthesis Model Version 3.3.16. NOAA Fisheries Service, Seattle. 165 pp.

Methot, R.D. and C.R. Wetzel. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142: 86–90.

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.

Punt, A.E., Smith, D.C., Krusic-Goulb, K., Robertson, S. 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Canadian Journal of Fisheries and Aquatic Sciences 65: 1991-2005

Punt, A.E. 2017. Some insights into data weighting in integrated stock assessments. Fish. Res. 192: 52-65. doi:10.1016/j.fishres.2015.12.006.

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

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

Rowling, K.R. 1994. Redfish, *Centroberyx affinis* in R.D.J. Tilzey (ed) The South East Fishery, Bureau of Resource Sciences, Canberra.

Rowling, K.R. 1999. Stock Assessment Report for Redfish, 1999. Redfish Assessment Group, South East Fishery Assessment Group, Australian Fisheries Management Authority, Canberra.

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

Thomson, R.B. 2002. Integrated Analysis of redfish in the South East Fishery, including the 2001 fishing data. Report to Redfish Assessment Group, Bermagui, 27-28 June 2002.

Thomson, R.B. and Klaer, N. 2011. South East Fishery data for stock assessment purposes. Technical document.

Thomson, R., Burch, P., Fuller, M., Deng, R., Althaus, F. 2019. Data summary for the Southern and Eastern Scalefish and Shark Fishery: Logbook, Landings and Observer Data to 2018. Unpublished report to SERAG Meeting.

Tuck, G.N. 2014. Stock assessment of redfish *Centroberyx affinis* based on data up to 2013: Supplement to the October 2014 Shelf RAG paper. Technical document presented to the Shelf RAG, 22 November 2014.

Tuck, G.N. and Day, J.R. (2014) Stock assessment of redfish *Centroberyx affinis* based on data to 2013. pp 103 - 147 in Tuck, G.N. (ed.) 2015. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2014. Part 1. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 170p.

Tuck, G., Day, J., Haddon M. and Castillo-Jordán, C. (2017) Redfish (*Centroberyx affinis*) stock assessment based on data to 2016. pp 691 - 729 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.

Waterhouse, L., Sampson, D.B., Maunder, M., Semmens, B.X. 2014. Using areas-as-fleets selectivity to model spatial fishing: asymptotic curves are unlikely under equilibrium conditions. Fish. Res. 158, 15–25.

Wise, B., and Thomson, R.B. 2002. Stock Assessment Report for Redfish, 2002. Redfish Assessment Group, South East Fishery Assessment Group, Australian Fisheries Management Authority, Canberra.

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