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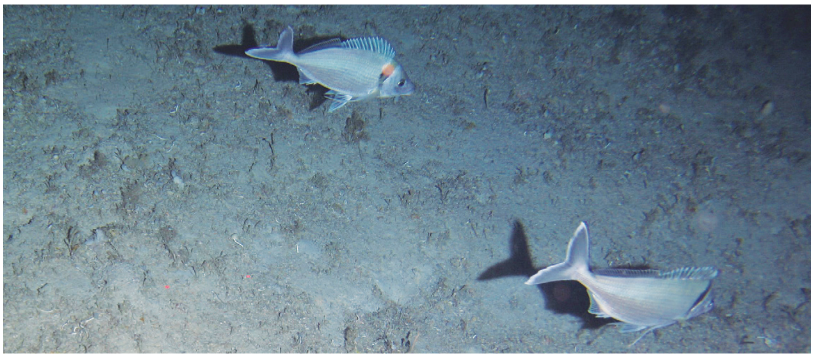
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2018 and 2019



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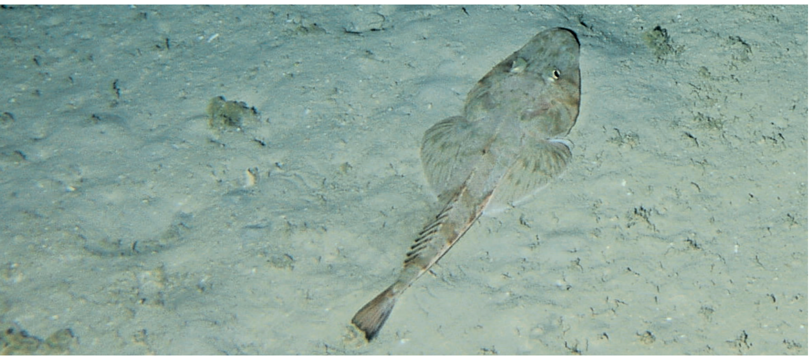

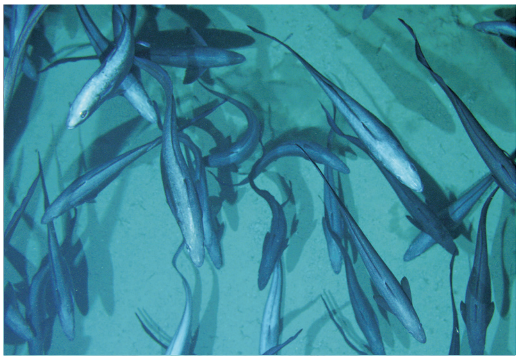

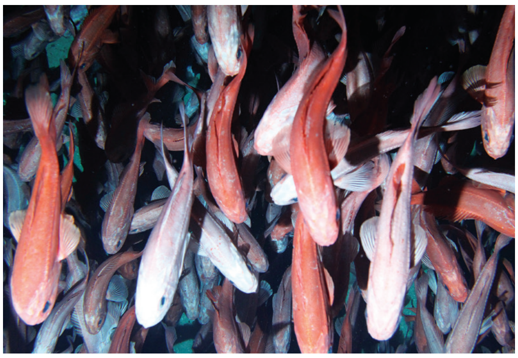

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Cover photographs

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

Report structure

Part 1 of this report describes the Tier 1 assessments of 2019. Part 2 describes the Tier 3 and Tier 4 assessments, catch rate standardisations and other work contributing to the assessment and management of SESSF stocks in 2019.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2018 and 2019

Part 1: 2019

G.N. Tuck
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Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2019

TABLE OF CONTENTS

10. Bight Redfish (*Centroberyx gerrardi*) stock assessment based on data to 2018-19

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10.1 Executive Summary

This document presents the agreed base case for the Tier 1 Bight Redfish (*Centroberyx gerradi*) assessment for presentation at the second GABRAG meeting in December 2019. The last full assessment was presented in Haddon (2015). The base case has been updated by the inclusion of data up to the end of 2018-19, which entails an additional four years of catch, CPUE, length and age data and ageing error updates since the 2015 assessment, and incorporation of survey results from the 2017-18 from the GAB Fishery Independent Survey (GAB-FIS). The process used to develop a preliminary base case for Bight Redfish through the sequential updating of recent data and updating the stock assessment package Stock Synthesis (SS-V3.30.14) was presented in November 2019. This document provides further detail of the agreed base case, with RBC values and sensitivities to the base case model structure.

Exploration of the initial ageing error matrix highlighted issues relating to both the size of the data set and the influence of a small number of old fish on the results. An updated ageing error matrix resolved these issues and also reduced a spike in the last recruitment estimate (2003). This updated ageing error matrix was presented as a sensitivity in November 2019 and was accepted as the agreed base case.

As seen in November 2019, results show poor fits to the CPUE and FIS abundance series, but reasonable fits to length and conditional age-at-length data. This assessment estimates that the projected 2020-21 spawning stock biomass will be 64% of virgin spawning stock biomass (B_0), compared to 62% B_0 at the start of 2016-17 from the 2015 assessment (Haddon, 2015) and 90% B_0 at the start of 2012-13 from the 2011 assessment (Klaer, 2011). The 2020-21 Recommended Biological Catch (RBC) under the 20:35:41 harvest control rule is 1,024 t. The average RBC over the three-year period 2020-21: 2022-23 is 963 t. The long-term RBC is 912 t.

Eighteen sensitivities to the base case model structure were examined. The results are very sensitive to the assumed value for natural mortality (*M*) and quite sensitive to the exclusion of the CPUE index. However, both of these sensitivities result in considerably larger likelihoods, with deterioration in the fits to the age and survey data respectively.

10.2 Introduction

10.2.1 *The fishery*

The trawl fishery in the Great Australian Bight (GAB) primarily targets two species, Bight Redfish (*Centroberyx gerrardi*) and Deepwater Flathead (*Neoplatycephalus conatus*), and these have been fished sporadically in the GAB since the early 1900s (Kailola et al., 1993). The GAB trawl fishery (GABTF) was set up and managed as a developmental fishery in 1988, and since then a permanent fishery has been established with increasing catches of both species, although catches of Bight Redfish have declined recently. Bight Redfish are endemic to southern Australia, occurring from off Lancelin in WA to Bass Strait in depths from 10 m to 500 m. Deepwater Flathead are also endemic to Australia and inhabit waters from NW Tasmania, west to north of Geraldton in WA in depths from 70 m to more than 490 m (Kailola et al., 1993; www.fishbase.org). The two species are often caught in the same trawl tows although Bight Redfish is most commonly taken in the east of the GAB.

10.2.2 *Previous assessments*

An initial stock assessment workshop for the GABTF held in 1992 focused on the status of Deepwater Flathead and Bight Redfish. Sources of information for the workshop included historical data, logbook catch data, observer data and biological information. With so few years of data available at that time, catch-per-unit-area (kg/km^2) was calculated for quarter-degree squares and then scaled to the total area in which the species had been recorded. The approximate exploitable biomass estimates for Deepwater Flathead and Bight Redfish obtained by this crude method were 32,000 t and 12,000 t respectively (Tilzey and Wise, 1999). Large uncertainties in the method prevented calculation of error bounds.

Wise and Tilzey (2000) produced the first attempt to assess the status of Bight Redfish using an age- and sex-structured stock assessment model. The virgin total biomass estimates for the base case model was 9,095t (4,924 – 13,266 t). In 2002 an updated assessment was carried out for Bight redfish and the unexploited biomass estimates for the base case model was then 9,563 t (8,368 – 10,759 t).

GABTF assessments in 2005 (Wise and Klaer, 2006; Klaer, 2006) used a custom-designed integrated assessment model developed using the AD Model Builder software (Fournier et al., 2012). A series of fishery-independent resource surveys was also commenced in 2005, providing a single annual biomass estimate for Bight Redfish and Deepwater Flathead (Knuckey et al., 2015), plus extra samples of length and age composition data. Initially, attempts were made to make absolute abundance estimates using classical swept area methods from the survey data. The unexploited biomass level estimated using this approach was 13,932 t and current depletion level was estimated at 75% for Bight Redfish.

The 2006 assessment (Klaer and Day, 2007) duplicated as far as possible the assessment results from 2005 using the Stock Synthesis (SS) framework. Although it was possible to replicate 2005 results reasonably well, there were a few differences in the model structure implemented in Stock Synthesis including calculation of recruitment residuals independently and allowing recruitment residuals to occur prior to the commencement of the fishery.

An attempt was made to incorporate as much previously unused data as possible into the 2007 assessment - particularly length-frequencies (Klaer, 2007). Age-frequencies were no longer used explicitly but conditional age-at-length distributions were obtained from age-length keys. In addition, the model used original age-at-length measurements to fit growth curves within the model, to better allow for the interaction between selectivity and the growth parameters. Depletion of Bight Redfish in 2007 was estimated at 82%, and the unexploited female spawning biomass was estimated at 18,685 t.

The model structure for the 2009 assessment for Bight Redfish (Klaer, 2010) was similar to the 2007 assessment, but used a more recent version of Stock Synthesis. Differences were the use of the fishery independent survey as a relative abundance index, estimation of fewer growth parameters, estimation of the natural mortality rate, and adjustment of the relative weighting of abundance indices versus length and age composition information. The unexploited female biomass was estimated at 12,272 t and the depletion at 77%.

In 2011, the Bight Redfish assessment was updated using the latest version of Stock Synthesis (SS-V3.21d) and the most recent data on ISMP collected length and age composition as well as the standardized CPUE and FIS estimates of relative abundance (Klaer, 2012a,b). This led to an estimate of unfished female spawning biomass of 26,210 t and a spawning biomass depletion estimate of 90%.

In 2015, the Bight Redfish assessment was updated using version SS-V3.24U (Methot and Wetzel, 2013; Methot, 2015) and the most recent data on ISMP collected length and age composition as well as the standardized CPUE and FIS estimates of relative abundance (Haddon, 2014a,b; Sporcic, 2015). This led to an estimate of unfished female spawning biomass of 5,451 t and a spawning biomass depletion estimate of 63%.

10.2.3 *Modifications to the previous assessment*

A preliminary base case was developed and presented to GABRAG in November 2019. This was used to describe the changes made to the previous assessment by the sequential addition of the new data now available along with other minor modelling changes.

The latest version of Stock Synthesis was used (SS-V3.30.14.05; Methot et. al., 2018) and data updates were implemented. The usual process of bridging to a new model was conducted, by adding new data piecewise and analysing which components of the data contributed to changes in the assessment outcome (Sporcic et al., 2019).

10.3 Methods

10.3.1 *Data and model inputs*

10.3.1.1 Biological parameters

Male and female Bight Redfish are assumed to have the same biological parameters except for the length-weight relationship.

Three of the four parameters relating to the von Bertalanffy growth equation are estimated within the model-fitting procedure from the observed age-at-length data. This approach attempts to account for the impact of gear selectivity on the age-at-length data collected from the fishery and any impacts of ageing error.

The rate of natural mortality per year, M, is estimated in the base case model, with the estimated value being close to 0.1. A likelihood profile was constructed, as the model outcomes are very sensitive to this parameter, where M is given a series of fixed values and all other parameters are re-fitted to determine the effect on the total likelihood and individual components of the likelihood.

Maturity is modelled as a logistic function, with 50% maturity at 25 cm. Fecundity-at-length is assumed to be proportional to weight-at-length.

The assessment data for Bight Redfish comes from a single trawl fleet; although there is now a Danish seine vessel operating and some pair-trawling occurring in the GAB, but only catching a very small quantity of Bight Redfish.

10.3.1.2 Fleets

The assessment data for Bight Redfish come from one fleet. However, the data from that fleet have been separated into four sub-fleets which allow for potential differences in selectivity/availability:

a) Trawl Onboard measurements

b) Trawl Port measurements

c) Trawl Industry collected measurements

d) Trawl GAB-FIS measurements

10.3.1.3 Landed catches

A landed catch history for Bight Redfish is available for the years from 1988-89 to 2018-19 (Figure 10.1; Table 10.1). Landed catches were derived from GAB logbook records for the years to 2005-06 and catch disposal records have been the source of total landings since then. All landings were aggregated by financial year.

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April. As the assessment is conducted according to financial year, the recent quota year change has resulted in closer alignment of the assessment and quota years. In the intervening year the quota year was extended to 16 months to allow for this change, which is one reason catches were elevated in the 2006-07 financial year (Table 10.1).

In order to calculate the Recommended Biological Catch (RBC) for 2020-21, it is necessary to estimate the financial year catch for 2019-20. TACs have been substantially under-caught in recent years and so the 2019-20 catch was assumed to be the same as the catch in 2018-19 (215 t).

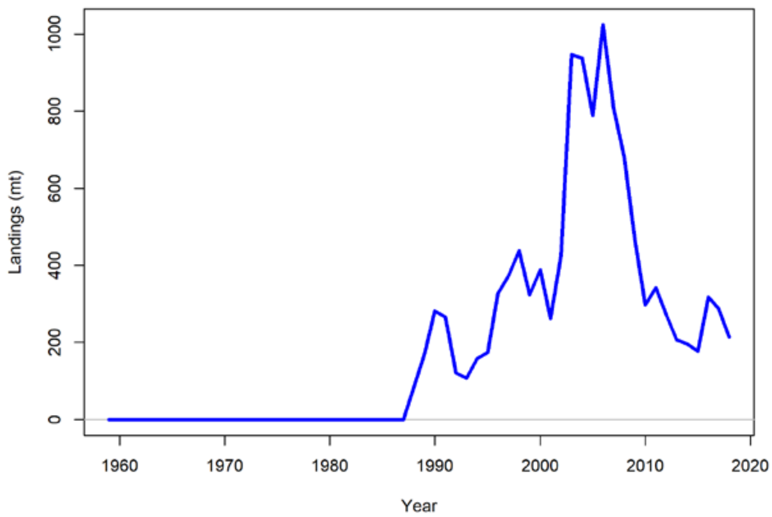

Figure 10.1. Total reported landed catch of Bight redfish from 1987-88 to 2018-19 (see Table 1).

10.3.1.4 CPUE indices

Data from the GAB fishery used in the CPUE analysis was based on depths between 0 – 1000 m, taken by Trawl. Also, analyses were restricted to vessels present for more than two years and which caught an average annual catch > 4 t, and for trawl shots more than one hour but less than 10 hours. Instead of five-degree zones across the GAB, 2.5-degree zones were employed to allow better resolution of location, based differences in CPUE. Also, a depth range of 50 – 300 m was used in the analysis. Catches in 1986-87 were relatively low and only taken by a single vessel and so were omitted from analysis (Sporcic, 2015, p209) and also omitted from the current CPUE analysis (Sporcic, 2019a,b). Annual standardized CPUE used in the stock assessment model are tabulated in Table 10.1.

Table 10.1. Financial year values of catch, standardized CPUE (Trawl) and GAB_FIS from 1988-89 to 2018-19. Catch is taken from logbook estimates until 2005-06. Subsequently, CDR catches are used to 2014-15 (Haddon, 2015) and catches from 2015-16 to 2018-19 from CDR landings database. Discards are assumed to be trivial. Standardized CPUE are from Sporcic (2019a,b). GAB-FIS abundance indices are from Knuckey et al. (2015) and Knuckey et al. (2018). ^: Interpolated GAB-FIS (bold; see sensitivity Section 3.3: Case 16).

Season	Catch (t)	CPUE	GAB-FIS	INTERPOLATED GAB-FIS^
1987-88		2.5623		
1988-89	85.65	2.4517		
1989-90	170.83	1.5382		
1990-91	281.81	1.4084		
1991-92	265.61	1.2932		
1992-93	120.70	0.9523		
1993-94	107.47	0.9084		
1994-95	157.80	0.6177		
1995-96	173.92	0.7349		
1996-97	327.18	0.8966		
1997-98	372.62	0.9406		
1998-99	437.79	1.1019		
1999-00	323.64	0.9718		
2000-01	387.88	0.8591		
2001-02	262.61	0.673		
2002-03	424.67	0.7201		
2003-04	946.48	0.9862		
2004-05	937.46	0.954	20887	20887
2005-06	789.70	0.9101	25380	25380
2006-07	1023.91	0.9977	25713	25713
2007-08	808.02	0.9275	14591	14591
2008-09	681.89	0.9927	27610	27610
2009-10	469.70	0.9282		
2010-11	297.60	0.7396	13189	13189
2011-12	341.48	0.742		**10535**
2012-13	273.45	0.6629		**7881**
2013-14	207.05	0.5994		**5227**
2014-15	196.56	0.6496	2573	2573
2015-16	176.95	0.6367		**3066**
2016-17	317.09	0.8866		**3560**
2017-18	288.49	0.918	4053	4053
2018-19	214.50	0.8385		

10.3.1.5 Age composition data

An estimate of the standard deviation of age reading error was calculated by Andre Punt (pers. comm., 2019) from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 10.2).

Age-at-length measurements, based on sectioned otoliths, provided by Fish Ageing Services, were available for the years 1990, 1992-94, 1996-97, 1999-01, 2003-08, 2010-17 for otoliths collected onboard and from 2005, 2008, 2010, 2014 for otoliths collected at port (Table 10.3).

Table 10.2. Standard deviation (SD) of age reading error (A Punt pers. comm. 2019).

AGE	SD	AGE	SD
0.5	0.04417	32.5	1.41344
1.5	0.04417	33.5	1.45761
2.5	0.08834	34.5	1.50178
3.5	0.13251	35.5	1.54595
4.5	0.17668	36.5	1.59012
5.5	0.22085	37.5	1.63429
6.5	0.26502	38.5	1.67846
7.5	0.30919	39.5	1.72263
8.5	0.35336	40.5	1.7668
9.5	0.39753	41.5	1.81097
10.5	0.4417	42.5	1.85514
11.5	0.48587	43.5	1.89931
12.5	0.53004	44.5	1.94348
13.5	0.57421	45.5	1.98765
14.5	0.61838	46.5	2.03182
15.5	0.66255	47.5	2.07599
16.5	0.70672	48.5	2.12016
17.5	0.75089	49.5	2.16433
18.5	0.79506	50.5	2.2085
19.5	0.83923	51.5	2.25267
20.5	0.8834	52.5	2.29684
21.5	0.92757	53.5	2.34101
22.5	0.97174	54.5	2.38518
23.5	1.01591	55.5	2.42935
24.5	1.06008	56.5	2.47352
25.5	1.10425	57.5	2.51769
26.5	1.14842	58.5	2.56186
27.5	1.19259	59.5	2.60603
28.5	1.23676	60.5	2.6502
29.5	1.28093	61.5	2.69437
30.5	1.3251	62.5	2.73854
31.5	1.36927	63.5	2.78271
		64.5	2.82688

Table 10.3. Number of age-length otolith samples included in the base case assessment by sub-fleet 1990-2017.

YEAR	ONBOARD	PORT	TOTAL
1990	45		45
1992	46		46
1993	224		224
1994	47		47
1996	113		113
1997	822		822
1999	595		595
2000	330		330
2001	558		558
2003	601		601
2004	538		538
2005	413	101	514
2006	473		473
2007	355		355
2008	207	295	502
2010	34	223	257
2011	201		201
2012	488		488
2013	332		332
2014	490	203	693
2015	403		403
2016	594		594
2017	354		354

10.3.1.6 Length composition data

The number of shots or days of length frequency data for retained components of catches is available for sub-fleets: Onboard: 2000-16, 2018; GAB-FIS: 2009-18; and Industry (days): 1992-93, 1999, 2002-05, 2014-17 (Table 10.4). Also, the number of trips of length frequency data for retained components of catches is available from Port for 2004-08, 2010, 2014 and 2017 (Table 10.4).

Table 10.4. Number of shots (onboard and GAB-FIS), days (industry) and trips (port) for length frequencies included in the base case assessment by sub-fleet 1992-2018.

YEAR	ONBOARD	PORT	INDUSTRY	GAB-FIS	TOTAL
1992			1		1
1993			2		2
1999			11		11
2000	45				45
2001	34				34
2002	19		4		23
2003	17		13		30
2004	72	36	17		125
2005	40	44	8		92
2006	22	39			61
2007	19	63			82
2008	33	15			48
2009	36			167	203
2010	11	40		13	64
2011	37			93	130
2012	29			146	175
2013	35			179	214
2014	61	43	70	69	243
2015	31		62	63	156
2016	26		58	15	99
2017		39	11	76	126
2018	22			82	104

10.3.1.7 Input data summary

Different data sources are available for the Bight Redfish assessment including catch (landings), standardized commercial CPUE, an index of relative abundance from the Fishery Independent Survey (GAB-FIS), conditional age-at-length data from the Integrated Scientific Monitoring Program (ISMP) and from the GAB-FIS, and length composition data from the ISMP (keeping port sampling separate from the onboard sampling), from the GAB-FIS, and from onboard crew sampling (Figure 10.2).

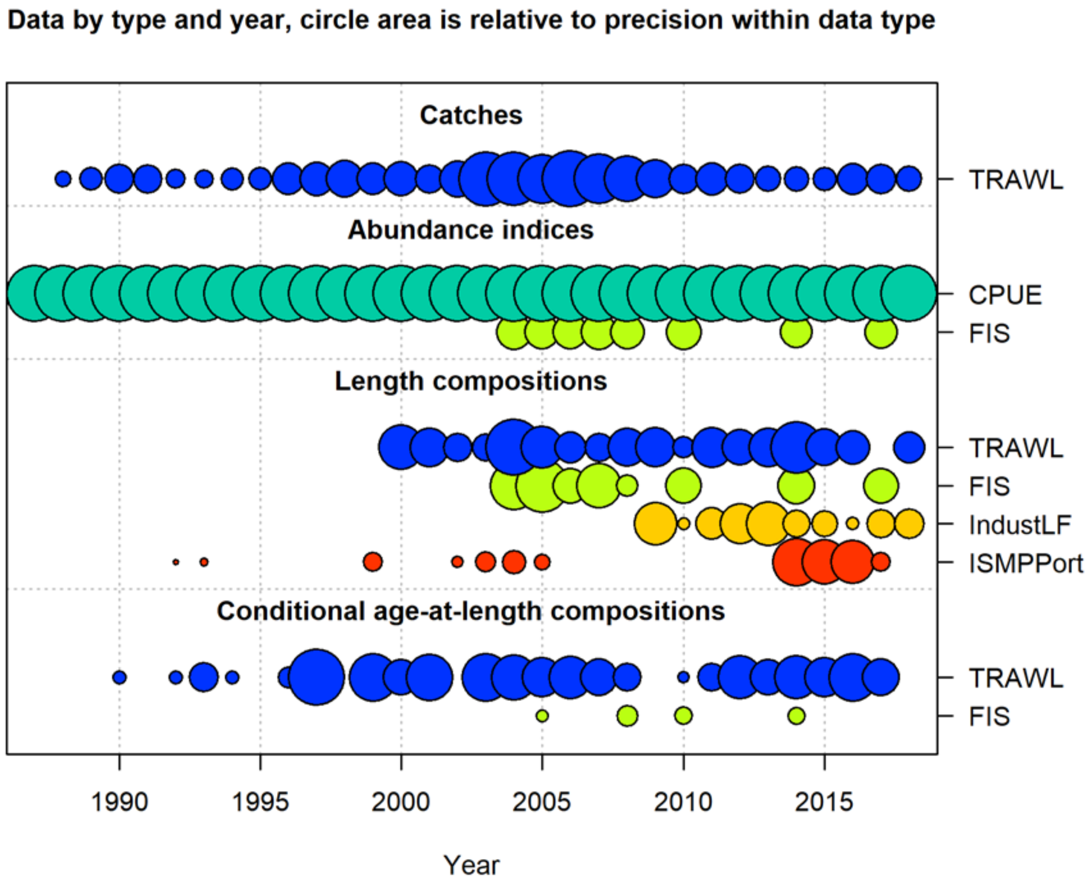

Figure 10.2. Data availability by type and year. The year axis denotes the start of the financial year, thus 1995 refers to 1995-96.

10.3.2 *Stock assessment method*

10.3.2.1 Population dynamics model and parameter estimation

A two-sex stock assessment for Bight Redfish was conducted using the software package Stock Synthesis version 3.30.14.05, (Methot et. al, 2019). Stock Synthesis is a statistical age- and length-structured model which allows multiple fishing fleets and can be fitted simultaneously to the range of data available for Bight Redfish. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are given fully in the Stock Synthesis technical description (Methot, 2005) and are not reproduced here. Some key features of the population dynamics model underlying Stock Synthesis which are pertinent to this assessment are discussed below.

a) Bight Redfish constitute a single stock within the area of the fishery.

b) The stock is assumed to be unexploited at the start of 1960 when the first recruitment deviations are estimated.

c) Catches used in this assessment are from 1988-89 (Haddon 2015) until 2018-19.

d) The CVs of all abundance indices (including the GAB-FIS) were initially set to the root mean squared deviation from a loess fit to the fleet specific indices (Sporcic, 2019a; Sporcic, 2019b) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

e) Four fishing sub-fleets are modelled.

f) Selectivity is assumed to vary among fleets, but the selectivity pattern for each separate sub-fleet is modelled as length-specific, logistic and time-invariant. The two parameters of the selectivity function for the trawl and GAB-FIS fleets are estimated within the assessment, with a common selectivity estimated (mirrored) for the industry, port and onboard trawl sub-fleets.

g) 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 at 0.1017 yr^{-1}.

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 is fixed at 0.75 for the base case analysis. Deviations from average recruitment at a given spawning biomass (recruitment residuals) are estimated from 1960 to 2003. Recruitment deviations are not estimated after 2003 because there are insufficient data to permit reliable estimation of recruitment residuals beyond 2003.

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 sixty-four years.

k) Growth of Bight Redfish is assumed to be time-invariant, that is there has been no change over time in the mean size-at-age, with the distribution of size-at-age determined from fitting the growth curve within the assessment using the age-at-length data. Differences in growth by gender are modelled.

l) The sample sizes for length and age frequencies were tuned for each sub-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 sub-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.

10.3.2.2 Relative data weighting

Iterative reweighting of input and output CVs or input and effective sample sizes is an imperfect but objective method for ensuring that the expected variation is comparable to the input (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 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.

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. Samples with less than 100 fish measured per year were excluded.

These initial sample sizes, based on shots and trips, are then iteratively reweighted so that the input sample size is equal to the effective sample size calculated by the model using the Francis weighting method for length data and the Punt weighting method for conditional age-at-length data.

10.3.2.3 Tuning procedure

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SS-V3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. Set the standard error for the log of the relative abundance indices (CPUE, acoustic abundance survey, or GAB-FIS) to their estimated standard errors for each survey or for CPUE (and GAB-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). Stock Synthesis 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. 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.

10.3.2.4 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith et al., 2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system 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. Bight Redfish 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_{targ}. Once this point is reached, the fishing mortality is set at F_{targ}. Day (2009) 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. An economic analysis was used to determine B_{MEY} (Kompas et al., 2012) and as a result, the 20:35:41 rule was used for Bight Redfish.

10.3.2.5 Sensitivity tests and alternative models

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 = 0.125 yr^{-1}
2. M = 0.075 yr^{-1}
3. h = 0.85
4. h = 0.65
5. 50% maturity at 23 cm
6. 50% maturity at 27 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. Halve the weighting on the age-at-length data
13. Double the weighting on the index (CPUE and GAB-FIS) data
14. Halve the weighting on the index (CPUE and GAB-FIS) data
15. Exclude the GAB-FIS series
16. Interpolate GAB-FIS values between 2010-14 and 2014-17
17. Exclude the CPUE series
18. Extend the recruitment deviations to 2005

The results of the sensitivity tests are summarized by the following quantities (Table 10.7):

1. SSB_0: the average unexploited female spawning biomass
2. SSB_{2020}: the female spawning biomass at the start of 2020-21

3. SSB_{2020}/SSB_0: the female spawning biomass depletion level at the start of 2020-21
4. RBC_{2020}: the recommended biological catch (RBC) for 2020-21
5. $RBC_{2020\text{-}22}$: the mean RBC over the three years from 2020-21 to 2022-23
6. $RBC_{2020\text{-}24}$: the mean RBC over the five years from 2020-21 to 2024-25
7. $RBC_{longterm}$: the longterm RBC

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

10.4 Results and Discussion

10.4.1 *The base case analysis*

10.4.1.1 Parameter estimates

Figure 10.3 shows the estimated growth curve for Bight Redfish, where the same set of parameters are estimated for males and females combined (Table 10.5). All growth parameters are estimated by the model except for L_{max} (parameter values are listed in Table 10.5).

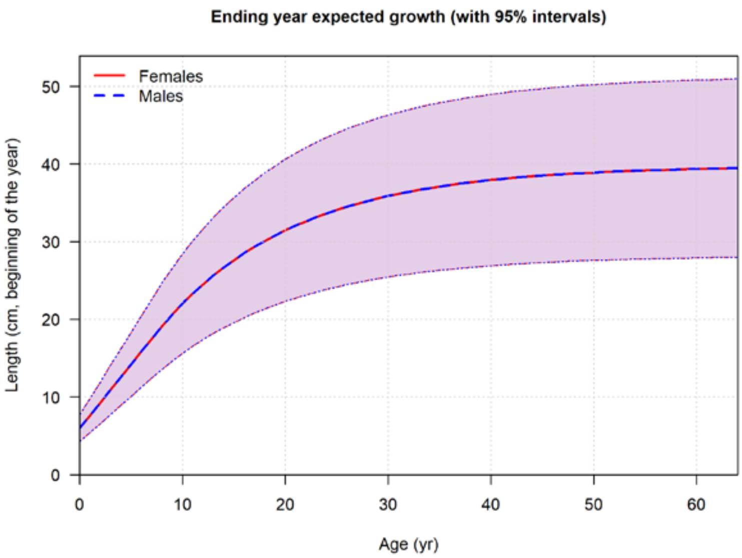

Figure 10.3. The model-estimated growth curves.

Selectivity is assumed to be logistic for all sub-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 industry, port and onboard length frequency data all have the same (mirrored) selectivity (red; Figure 10.4) with very similar selectivity to the GAB-FIS fleet (green; Figure 10.4).

Table 10.5. Summary of selected parameters from the 2019 base case model. Years represent the first year of each financial year e.g., 2015 refers to 2015-16.

Description	Parameter	Combined Male/Female	Comment(s)
Years	y	1960-2018	
Recruitment Deviates	r	estimated 1960 - 2003	
Fleets		1 Trawl only	
Discards		none significant, not fitted	
Age classes	a	0 – 64 years	
Sex ratio	p_s	0.5 (1:1)	fixed
Natural mortality	M	0.1017 per year	estimated
Steepness	h	0.75	fixed
Recruitment variation	σ_r	0.7	
Female maturity		25 cm (TL)	fixed
Growth	L_{max}	37.939 cm (TL)	fixed
	K	0.110936	fitted
	L_{min}	16.7648	fitted
	CV	0.131095	fitted
		Female	Male
Length-weight (based	f_1	0.0001 cm (TL)/gm	0.002
on standard length)	f_2	2.559	2.552

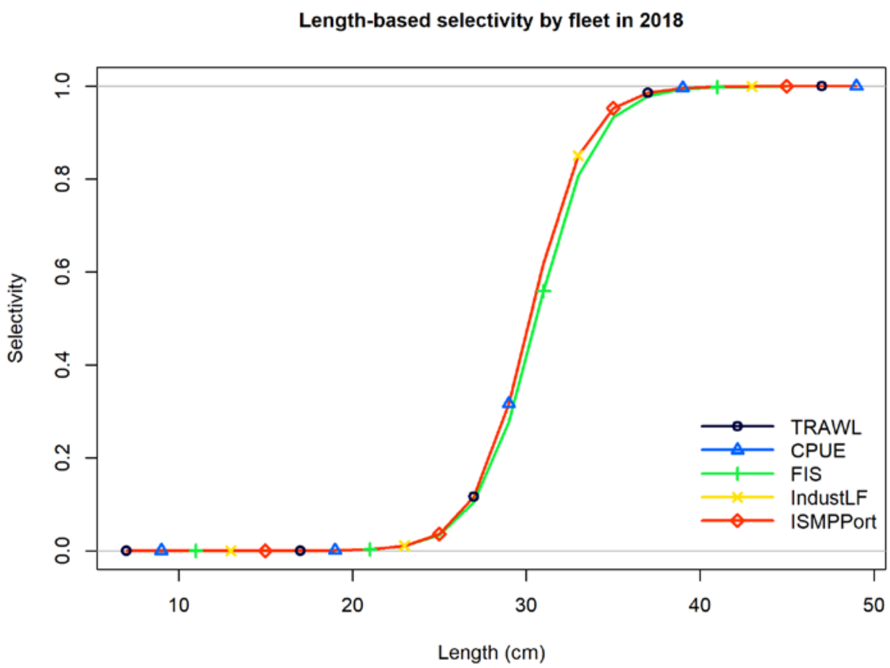

Figure 10.4. Selectivity functions by sub-fleet. The industry, port and onboard length frequency data all have the same (mirrored) selectivity (red), with very similar selectivity to the GAB-FIS sub-fleet (green).

10.4.1.2 Fits to the data

The fits to both the CPUE and GAB-FIS indices are poor (Figure 10.5). The model was not adequately able to fit the decline in the initial part of the CPUE series (i.e. 1987 to 1994). Given the longevity of this species, the modelled population dynamics are unable to reflect the more rapid changes observed in the CPUE series, both with the initial decline and later oscillations in the series. This may reflect environmentally driven availability.

The GAB-FIS estimates for 2014 and 2016 are considerably lower than the earlier GAB-FIS estimates (Figure 10.5). The fit to this series is a compromise between fitting the data up to 2010 and fitting the last two data points. As such, the influence of the last two points is to lower the overall fit to the series (which degrades the fit to the series up until 2010). As with the fits to the CPUE series, the modelled population dynamics cannot respond to the speed of the changes to the GAB-FIS indices.

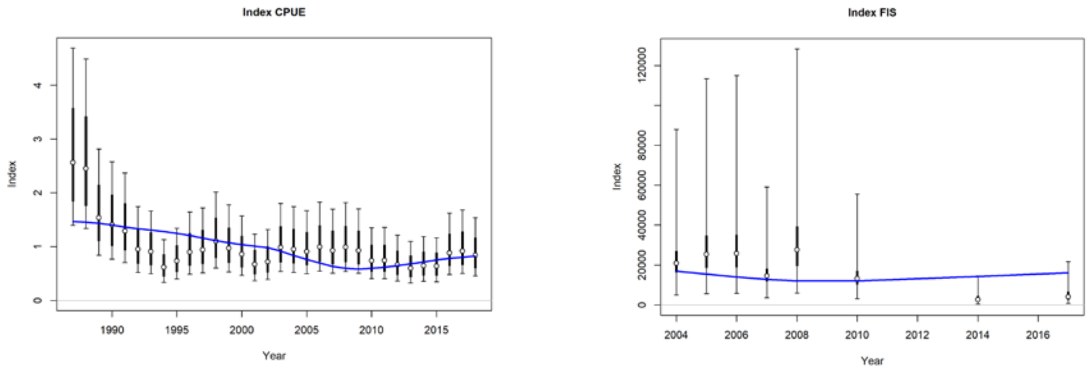

Figure 10.5. Annual Observed (circles) and model-estimated (lines) CPUE and GAB-FIS, with approximate 95% asymptotic intervals.

The base case model fitted the aggregated retained length-frequency distributions very well (Figure 10.6 and Appendix A)

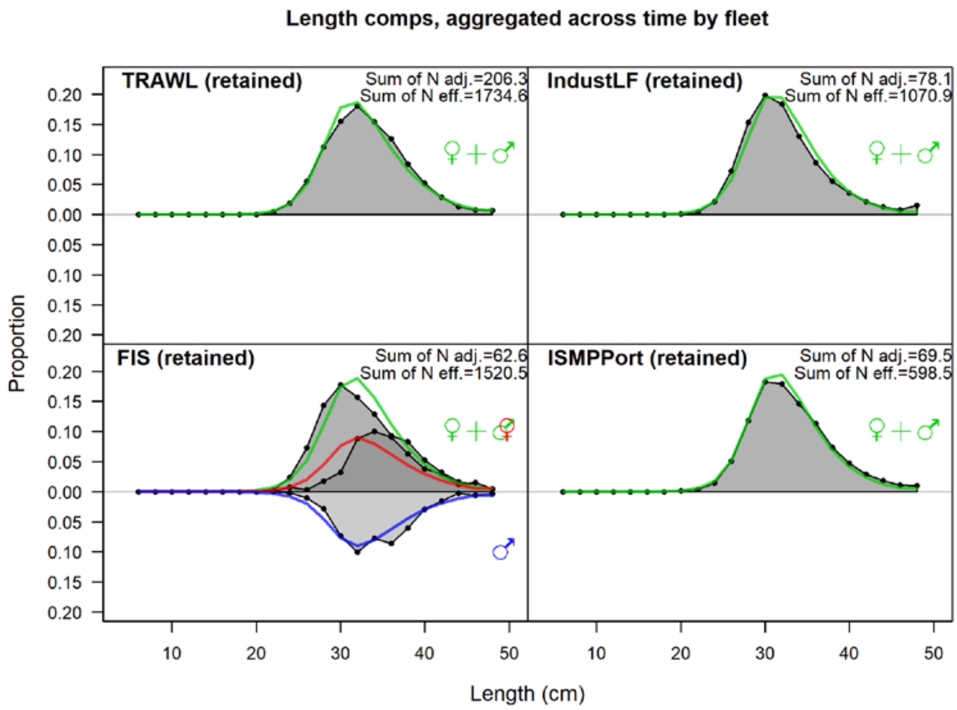

Figure 10.6. Fits to retained length compositions by fleet, separated by onboard, port and industry samples, aggregated across all years. Observed data are grey and the fitted values are shown in the green (male and female combined), red (female) and blue (male) lines.

The implied fits to the age composition data 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 included directly in the assessment. The model fits the observed age data reasonably well.

Note that there are separate implied fits to age for the 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, as the age data is not representative of the stock as a whole. This scaling up to length data can be done using either the onboard length data or the port length data – so it appears that there are two sets of age data.

The conditional age-at-length data is a little noisy between years, especially for the fleets with smaller catches. The mean age seen in the conditional age-at-length data varies between about 20 and 30 years for both trawl and GAB-FIS. This variability in the age-at-length data may be due to spatial or temporal variation in collection of age samples. The fits to conditional age-at-length are reasonable.

10.4.1.3 Assessment outcomes

Figure 10.7 shows the trajectory of spawning stock status. The stock declines steadily from the beginning of the fishery in 1988 to 2004 followed by a sharper decline to 2009 due to the increase in annual catch (over 800 t) between 2003-07. The stock increases steadily between 2010-18. The comparison to the base case from the 2015 assessment is shown in Figure 10.8.

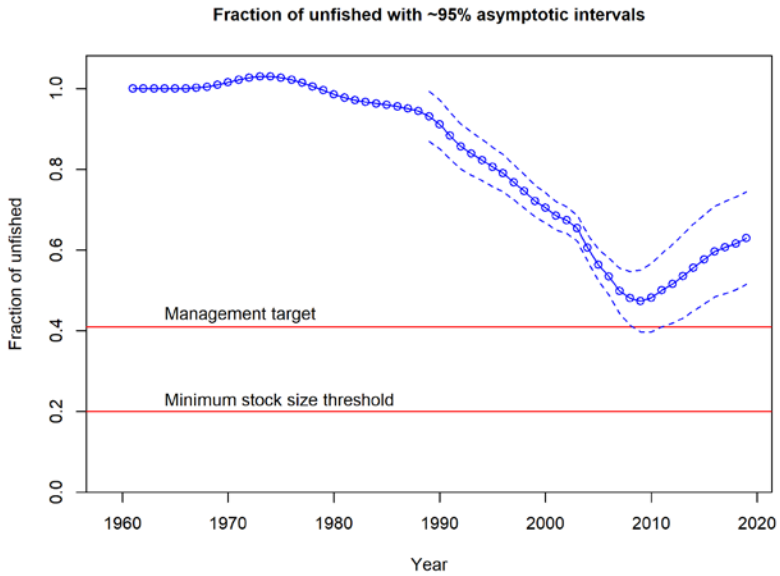

Figure 10.7. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the maximum posterior distribution (MPD) estimates for the base case analysis for Bight Redfish.

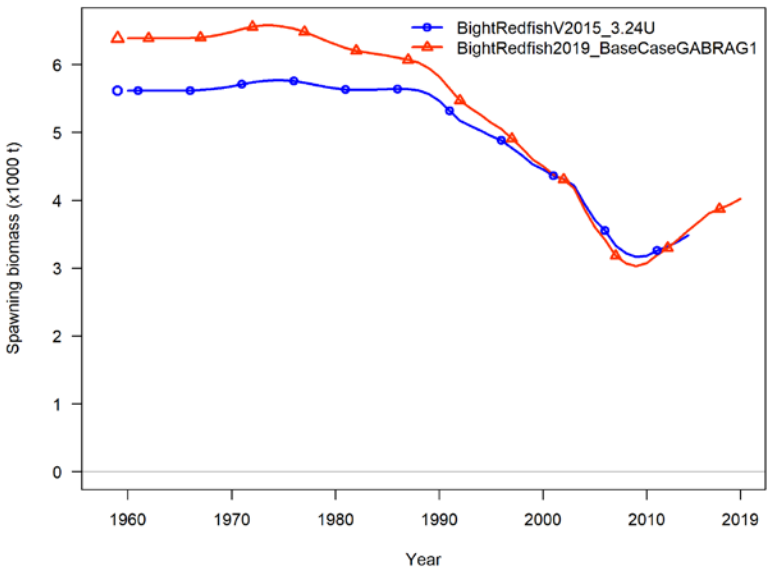

Figure 10.8. Time-trajectory of spawning biomass corresponding to the maximum posterior distribution (MPD) estimates for the base case analysis for the two base cases for the Bight Redfish assessment in 2015 and in 2019.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 10.9. Estimates of recruitments since about 1980 are generally variable. Notably, seven out of the last ten recruitment deviations are above average.

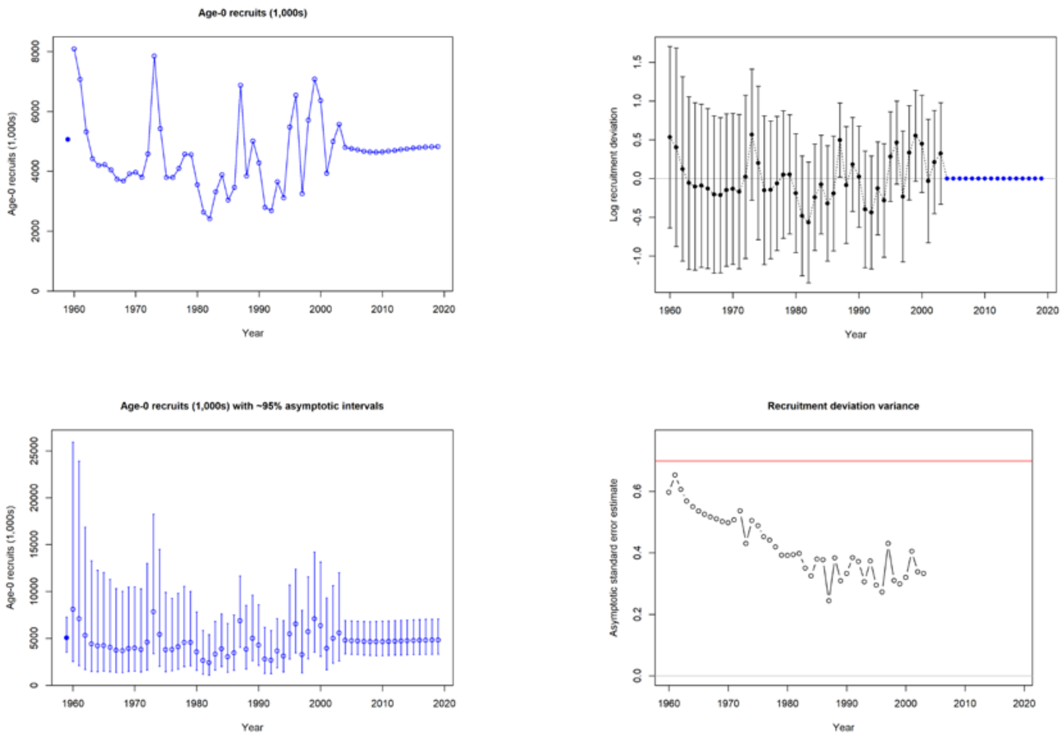

Figure 10.9. Recruitment estimation for the base case analysis. Top left: Time-trajectories of estimated recruitment numbers; Top right: time trajectory of estimated recruitment deviations; Bottom left: time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; Bottom right: the standard errors of recruitment deviation estimates.

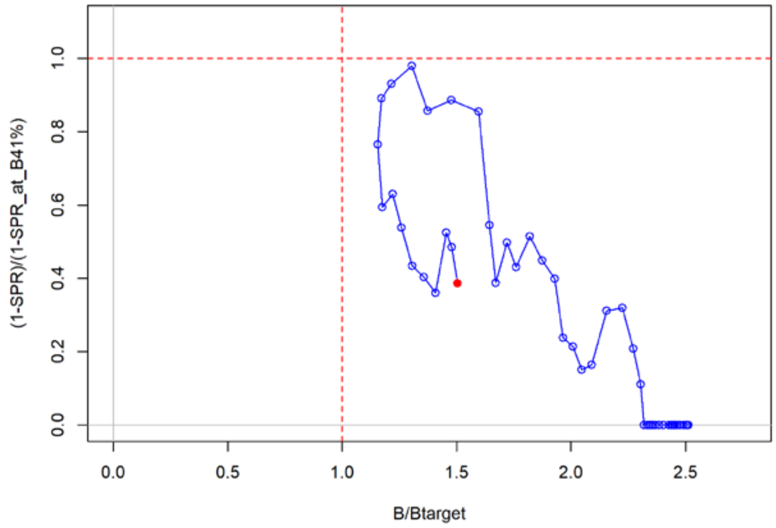

Figure 10.10. Kobe plot for the base case analysis, showing the trajectory of spawning biomass (relative to B_0) plotted against (1-SPR) as a ratio of the target, which is a proxy for fishing mortality, essentially integrating fishing mortality across fleets in the fishery.

Figure 10.10 shows a Kobe 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, in the bottom right corner, when there was low fishing mortality and high biomass to the present day (the red dot) with biomass above the target (to right of the vertical red dashed line) and the fishing mortality below the target fishing level (below the horizontal red dashed line). This trajectory shows an increase in overall fishing mortality and a decrease in biomass up until about 2009, with a subsequent decrease in fishing mortality and increase in biomass since then.

Figure 10.11 shows the fit to the stock recruitment relationship, with outlying years identified and the fit to the bias ramp.

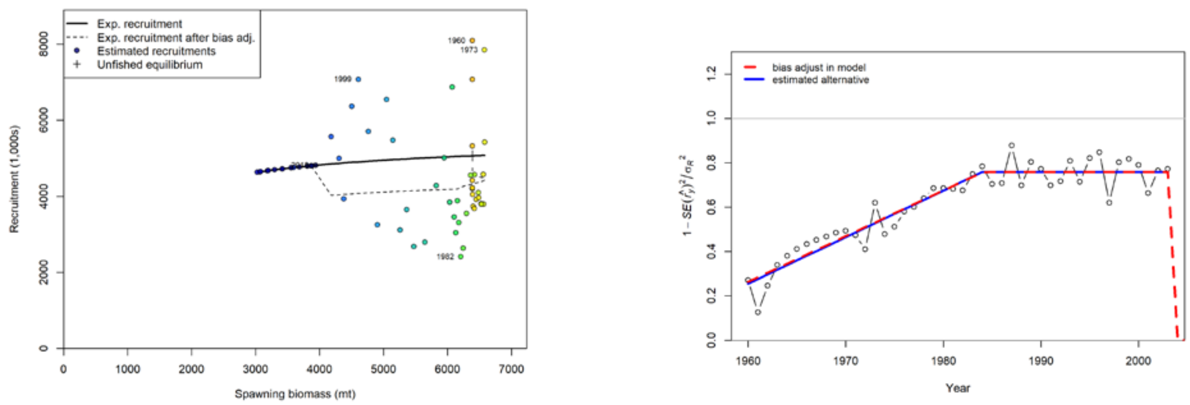

Figure 10.11. Recruitment estimation for the base case analysis. Left: the fitted stock-recruit curve and estimated recruitments; Right: bias adjustment.

The base case assessment estimates that current spawning stock biomass is 64% of unexploited stock biomass (SSB_0). The 2020 recommended biological catch (RBC) under the 20:35:41 harvest control rule is 1,024 t (Table 10.6) and the long term yield (assuming average recruitment in the future) is 607 t (Table 10.7). The average RBC over the three year period: 2020-2022 is 963 t (Table 10.7) and over the five year period 2020-2024, the average RBC is 912 t (Table 10.7). The RBCs for each individual year from 2020-24 are listed in Table 10.6 for the base case.

Table 10.6. Yearly projected RBCs (t) across all fleets under the 20:35:41 harvest control rules: assuming average recruitment from 2004.

YEAR	RBC (t)
2020	1024
2021	961
2022	905
2023	856
2024	813

10.4.2 *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 *M* 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 entire range of the 95% confidence interval, 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).

Standard parameters to consider are natural mortality (*M*), steepness (*h*), virgin spawning biomass (SSB_0), 2018 spawning biomass (SSB_{2018}) and spawning stock biomass relative to SSB_0 (depletion).

10.4.2.1 Natural mortality (M)

For Bight Redfish, the likelihood profile for natural mortality, *M*, is shown in Figure 10.12 and Figure 10.13 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This parameter is estimated in the model (M=0.1017 y^{-1}) and the likelihood profile suggests that it is well estimated. The index data (suggest higher mortality) and length data (suggest lower mortality) show some conflict. The age data are most influential on the total likelihood, with similar minimum values to the total likelihood. The confidence intervals on *M* are narrow ranging between approximately 0.093 and 0.11.

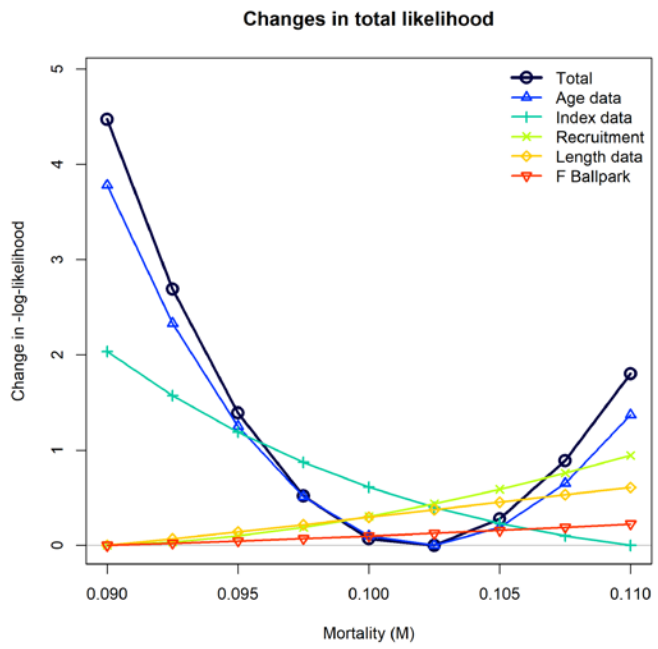

Figure 10.12. The likelihood profile for natural mortality (*M*), ranging from 0.09 to 0.11 yr^{-1}. The estimated value for *M* is 0.1017 yr^{-1}.

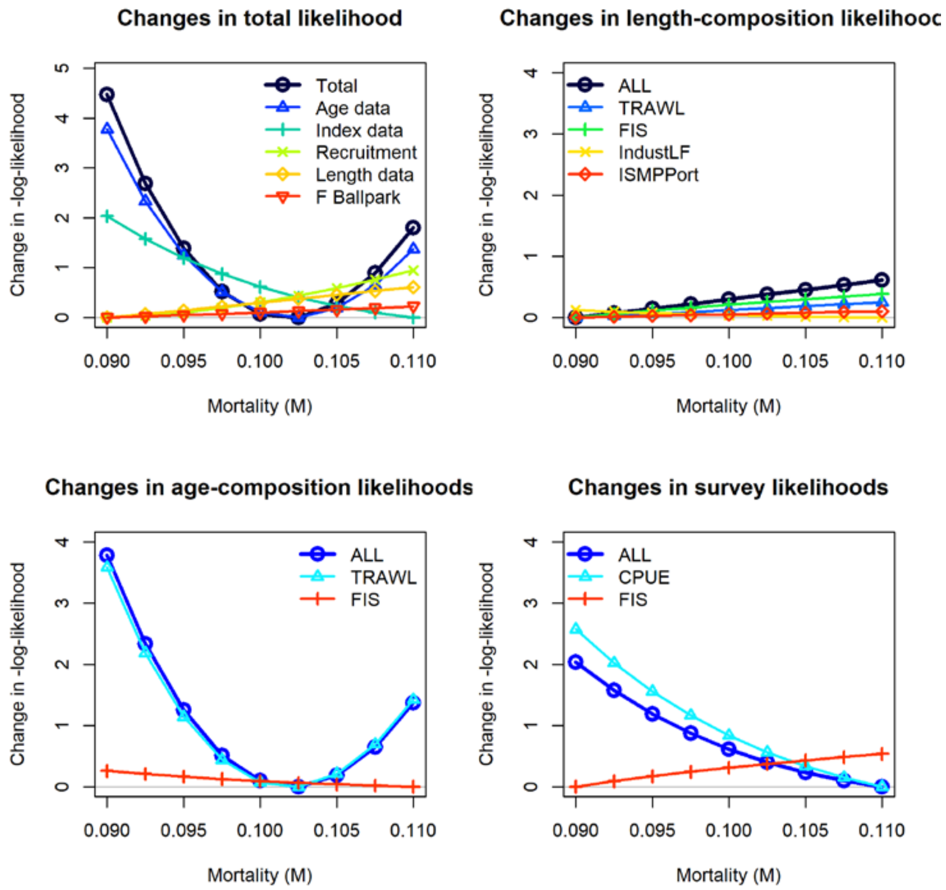

Figure 10.13. Piner plot for the likelihood profile for natural mortality (*M*), showing components of the change in likelihood for length, age and indices (CPUE; GAB-FIS) in addition to the changes in the total likelihood.

10.4.2.2 Steepness (h)

A likelihood profile on steepness, *h*, shows the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours (Figure 10.14). This figure shows that steepness cannot be well estimated, as the 95% confidence limits are not crossed (log-likelihood of 1.92 on the y-axis) by the total likelihood within the range considered (*h* = 0.6 to 0.8). This is not surprising given the stock in the base case model has not been depleted to levels that would enable steepness to be estimated. It is therefore reasonable to fix steepness at 0.75.

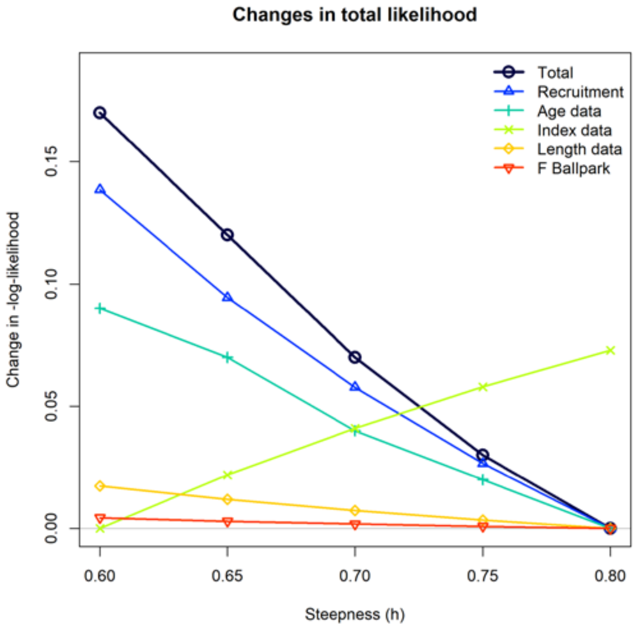

Figure 10.14. The likelihood profile for steepness (*h*), ranging from 0.6 to 0.8. The fixed value for *h* is 0.75.

10.4.2.3 Virgin spawning biomass (SSB_0)

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 10.15 and Figure 10.16 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 parameters R_0, which is the average equilibrium recruitment and constructing this likelihood profile. To construct a likelihood profile on SSB_0 requires setting up an additional "fleet" with a single data point (in 1960) 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. The likelihood profile suggests a broad range of plausible values for SSB_0 ranging between around 6,000 and 9,500 t with the most likely value at around 7,300 t. The important data sources in providing information on SSB_0 are the index data and age data (Trawl). SSB_0 needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing an upper bound on SSB_0 and the fits to the age data deteriorate with smaller values of SSB_0.

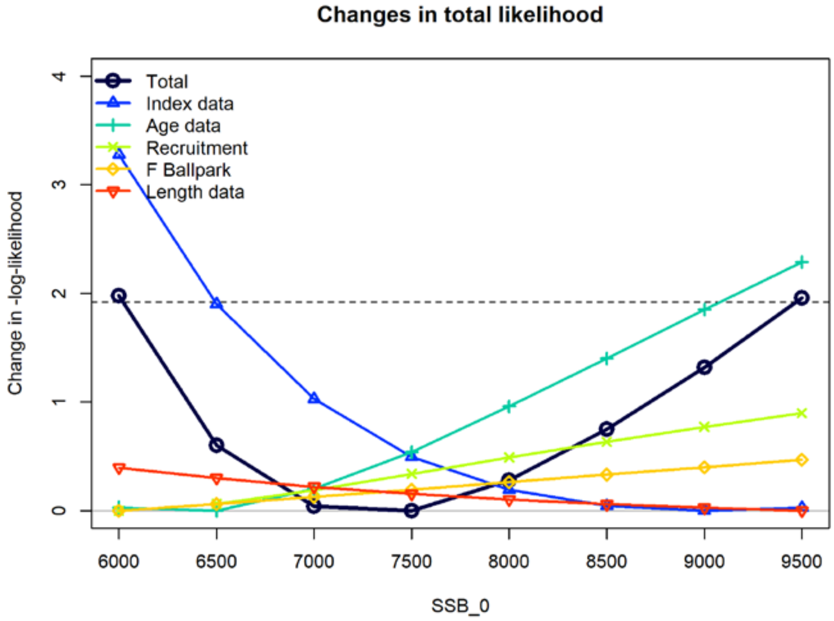

Figure 10.15. The likelihood profile for virgin spawning biomass, with SSB_0 ranging from 2,000 to 800 t. The estimated value for SSB_0 is 7,295 t.

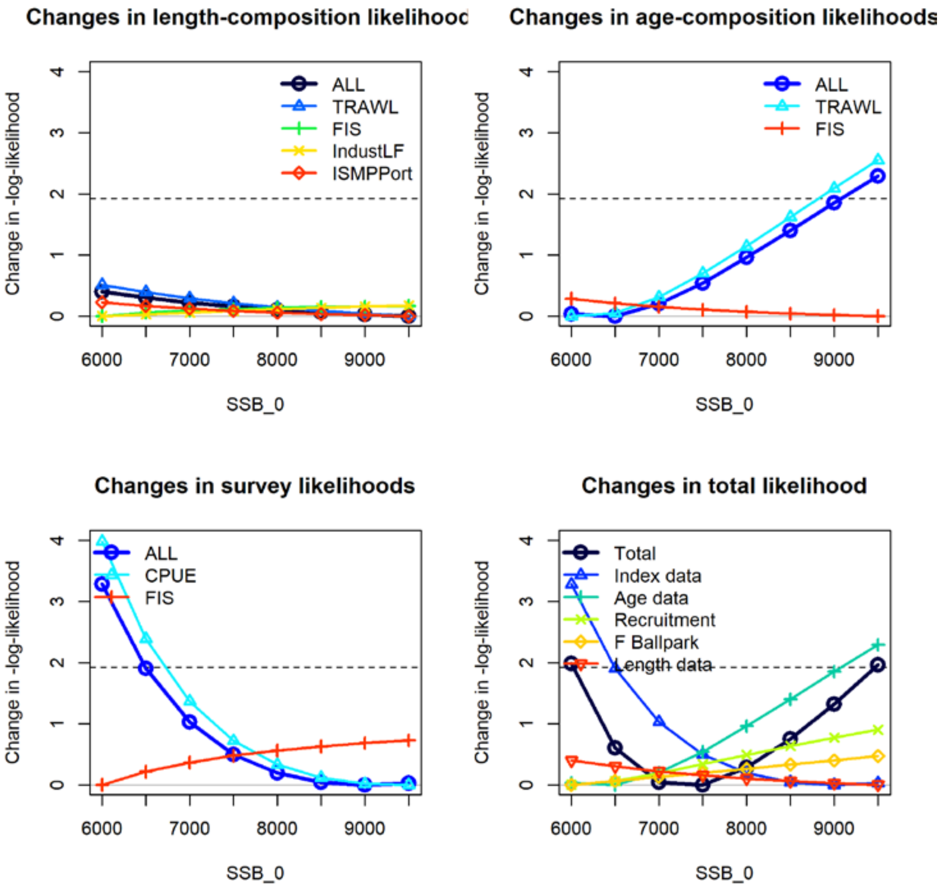

Figure 10.16. Piner plot for the likelihood profile for 2018 spawning biomass (SSB_0), showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

10.4.2.4 Current (2018) spawning biomass (SSB_{2018})

A likelihood profile for current (2018) spawning biomass (SSB_{2018}), using the same techniques as for SSB_0, is shown in Figure 10.17 and Figure 10.18 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours.

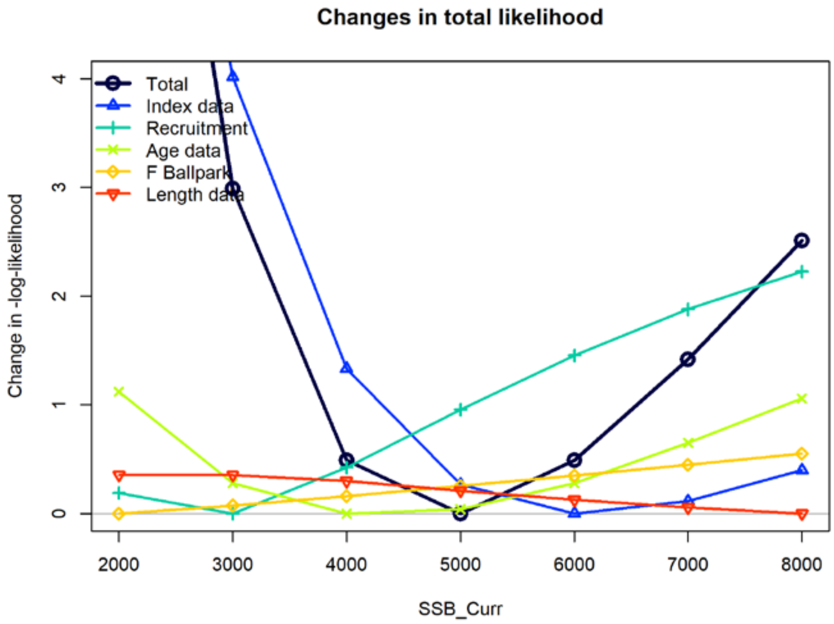

Figure 10.17. The likelihood profile for current (2018) spawning biomass, with SSB_{2018} ranging from 3,500 to 7,500 t. The estimated value for SSB_{2018} is 4,879 t.

This likelihood profile suggests a broad range of plausible values for SSB_{2018} ranging between around 3,500 and 7,500 t with the most likely value at around 4,900 t. The important data sources in providing information on SSB_{2018} are the index data and estimated recruitments. SSB_{2018} needs to be sufficiently high to enable the historical catches to be sustained, so this results in the recruitment component of the likelihood providing an upper bound on SSB_{2018} and the fits to the index data deteriorate with smaller values of SSB_{2018}.

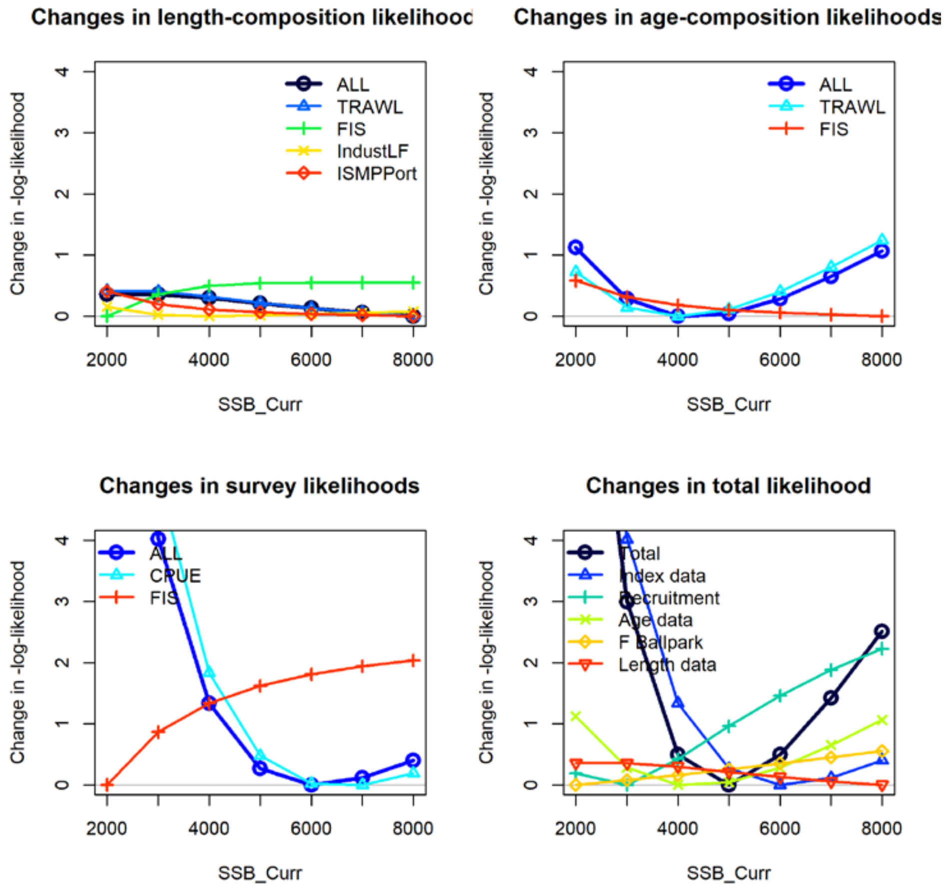

Figure 10.18. Piner plot for the likelihood profile for current (2018) spawning biomass (*SSB_{2018}*), showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

10.4.2.5 Relative Spawning Stock Biomass (Depletion)

A likelihood profile for current (2018) spawning stock biomass relative to SSB_0 (depletion) is shown in Figure 10.19 and Figure 10.20 with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. Note that depletion here is calculated for an earlier year (2018-19), so it does not require the projected catch in 2019-20. As such, the depletion implied from this likelihood profile is different to the estimated value reported above for the projected 2020-21 spawning stock biomass (70% of SSB_0).

This likelihood profile suggests a broad range of plausible values for depletion ranging between around 0.55 and 0.82 with the most likely value at around 0.65. The important data sources in providing information on depletion are the index data and estimated recruitments.

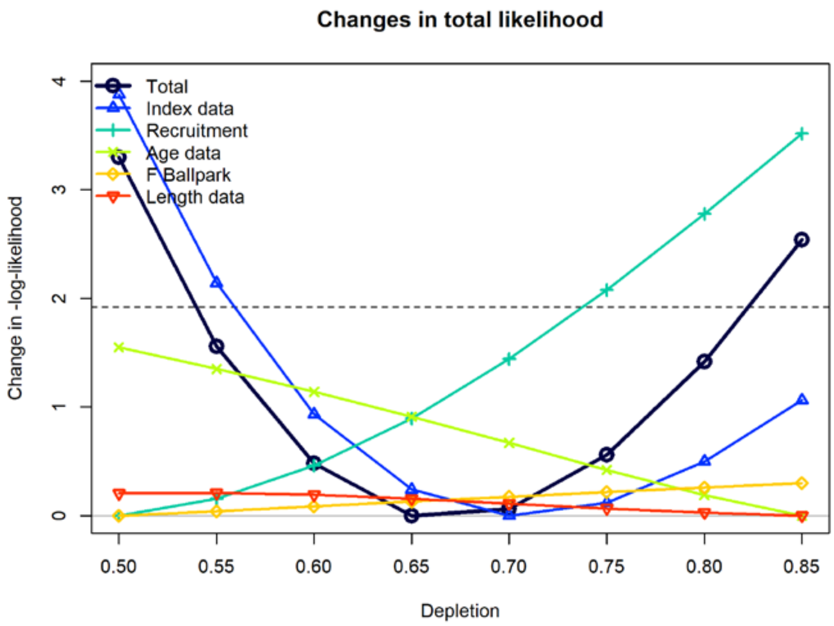

Figure 10.19. The likelihood profile for relative spawning stock biomass (depletion) in 2018, which suggests an optimal value of about 0.65 in 2018.

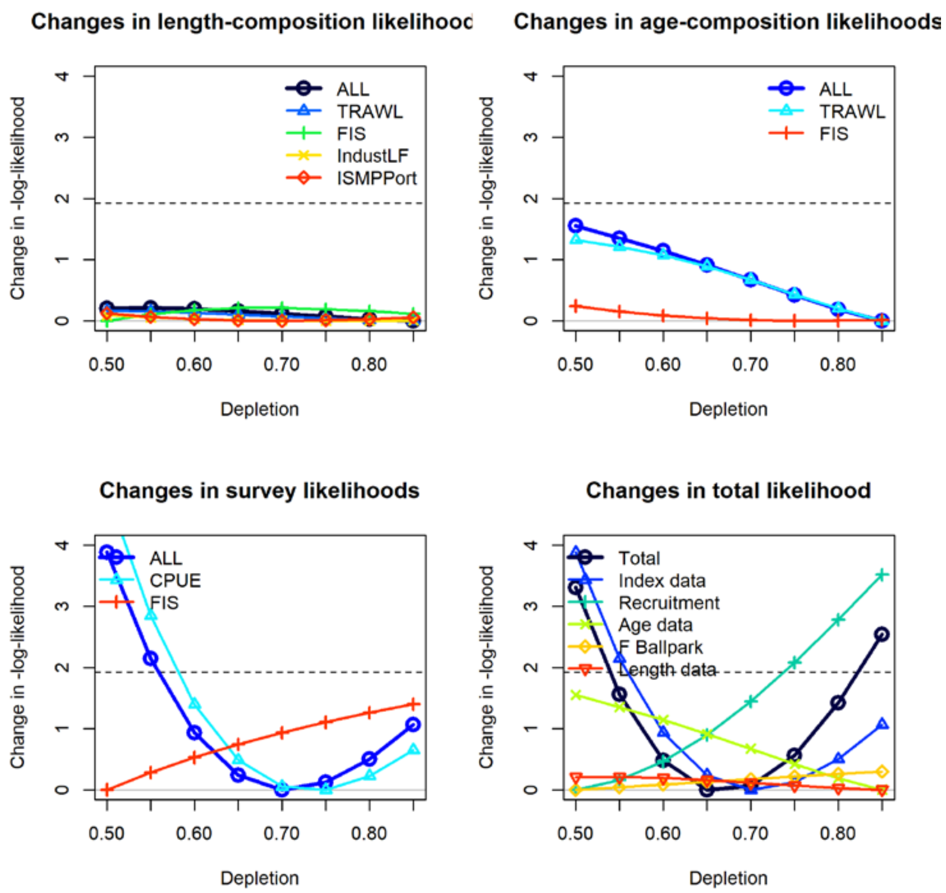

Figure 10.20. Piner plot for the likelihood profile for relative spawning stock biomass (depletion) in 2018-19, showing components of the change in likelihood for length, age and indices (CPUE, GAB-FIS) in addition to the changes in the total likelihood.

10.4.3 *Sensitivies*

Results of the sensitivity tests are shown in Table 10.7. The results are very sensitive to the assumed value for natural mortality (*M*). Much of this variability is due to the estimated current depletion level, which can be as low as 39% SSB_0 when *M* is 0.075. In addition, the results were quite sensitive when the CPUE index is excluded (i.e., using GAB-FIS as the only abundance index). It was somewhat sensitive to extending recruitment deviation estimates for an additional two years (i.e., up until 2005). However, this sensitivity produces unrealistically high recruitments in the last two years with little age and length data to inform them. Therefore, this sensitivity is unlikely to be considered as an acceptable alternative model. For all other standard sensitivities, there is limited variability in current depletion, ranging between 58% and 68% SSB_0. Adding additional interpolated FIS abundance indices made very little difference, to the estimates of spawning biomass or to the fits to the abundance indices.

Unweighted likelihood components for the base case and differences for the sensitivities largely show small (insignificant) changes in likelihood (Table 10.8). Sensitivities based on changes to *M* and excluding CPUE show considerably larger likelihoods (worse fits to: age in cases 1 and 2; survey in case 17).

Table 10.7. Summary of results for the base case and sensitivity tests. Recommended biological catches (RBCs) are only shown for agreed base case model (Case 0). Base case: 20:35:41; *M* 0.1017, *h* 0.75, 50% maturity 25 cm.

Case	Description	SSB_0	SSB_{2020}	SSB_{2020}/SSB_0	RBC_{2020}	$RBC_{2020-22}$	$RBC_{2020-24}$	$RBC_{longterm}$
0	Base case	6,387	4,093	0.64	1,024	963	912	607
1	*M* 0.125	8,854	6,909	0.78				
2	*M* 0.075	4,674	1,805	0.39				
3	*h* 0.85	6,369	4,160	0.65				
4	*h* 0.65	6,412	4,011	0.63				
5	50% maturity at 23 cm	6,939	4,598	0.66				
6	50% maturity at 27 cm	5,765	3,547	0.62				
7	$\sigma_R = 0.6$	6,016	3,850	0.64				
8	$\sigma_R = 0.8$	6,839	4,364	0.64				
9	wt x 2 length comp	6,398	4,058	0.63				
10	wt x 0.5 length comp	6,365	4,099	0.64				
11	wt x 2 age comp	5,886	3,566	0.61				
12	wt x 0.5 age comp	6,945	4,588	0.66				
13	wt x 2 index	7,023	4,792	0.68				
14	wt x 0.5 index	5,801	3,368	0.58				
15	no FIS	6,502	4,264	0.66				
16	Interpolate FIS	6,314	3,988	0.63				
17	No CPUE	4,910	2,196	0.45				
18	RecDev 2005	6,701	4,670	0.70				

Table 10.8. Summary of likelihood components for the base case and sensitivity tests. Likelihood components are unweighted, and cases 1-18 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Case	Description	Likelihood					
		TOTAL	Survey	Discard	Length comp	Age comp	Recruitment
0	Base case	1409.02	-19.29	0.00	41.21	1392.65	-5.94
1	*M* 0.125	10.12	-2.22	0.00	0.79	9.71	1.57
2	*M* 0.075	25.06	9.82	0.00	-0.81	15.62	0.62
3	*h* 0.85	-0.18	-0.01	0.00	-0.01	-0.13	-0.02
4	*h* 0.65	0.23	0.02	0.00	0.02	0.18	0.02
5	50% maturity at 23 cm	-0.03	-0.01	0.00	0.00	-0.02	0.00
6	50% maturity at 27 cm	0.02	0.01	0.00	0.00	0.02	0.00
7	$\sigma_R = 0.6$	-2.26	0.26	0.00	0.01	0.93	-3.43
8	$\sigma_R = 0.8$	2.03	-0.25	0.00	-0.01	-0.83	3.09
9	wt x 2 length comp	0.33	0.25	0.00	-0.72	0.80	-0.01
10	wt x 0.5 length comp	0.14	-0.12	0.00	0.54	-0.28	0.01
11	wt x 2 age comp	0.85	1.99	0.00	0.38	-2.16	0.70
12	wt x 0.5 age comp	1.17	-1.46	0.00	-0.49	3.90	-0.86
13	wt x 2 index	0.70	-1.73	0.00	0.17	2.05	0.14
14	wt x 0.5 index	0.77	2.66	0.00	-0.17	-1.40	-0.25
15	no FIS	-2.37	-2.66	0.00	0.06	0.09	0.13
16	Interpolate FIS	2.09	2.26	0.00	-0.04	-0.05	-0.08
17	No CPUE	17.35	20.44	0.00	-0.48	-2.10	-0.34
18	RecDev 2005	-1.90	-0.26	0.00	-0.12	-2.00	0.48

10.4.4 *Future work*

We attempted to incorporate two additional sensitivities (i) CPUE up to end of FY 2019 (i.e., adding two additional months) and (ii) 2018 conditional age at length data. Apparent issues with data quality and checking prevented these sensitivities being completed and presented in this report.

10.5 Acknowledgements

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10.7 Appendix A

A.1 Base case diagnostics

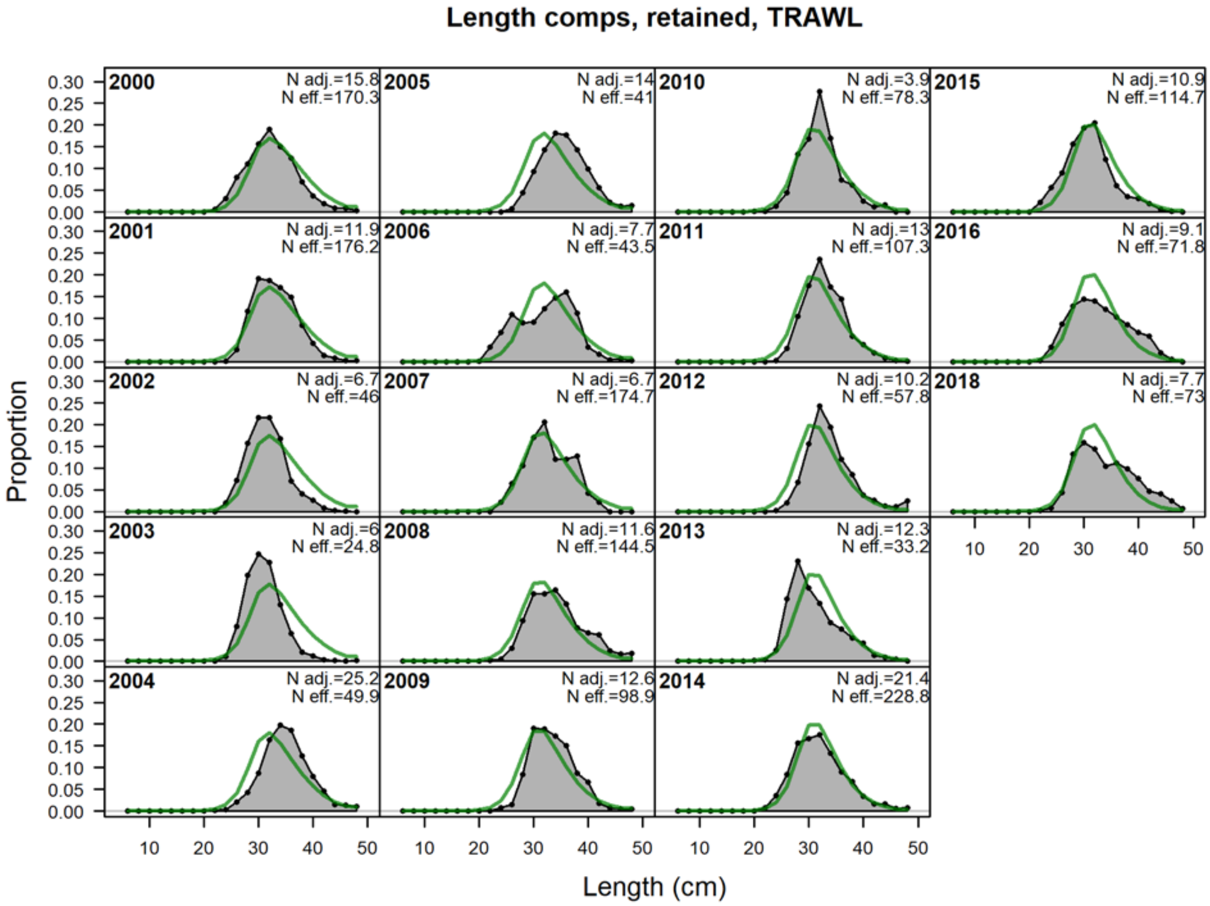

Figure A 10.1. Length composition fits - trawl retained.

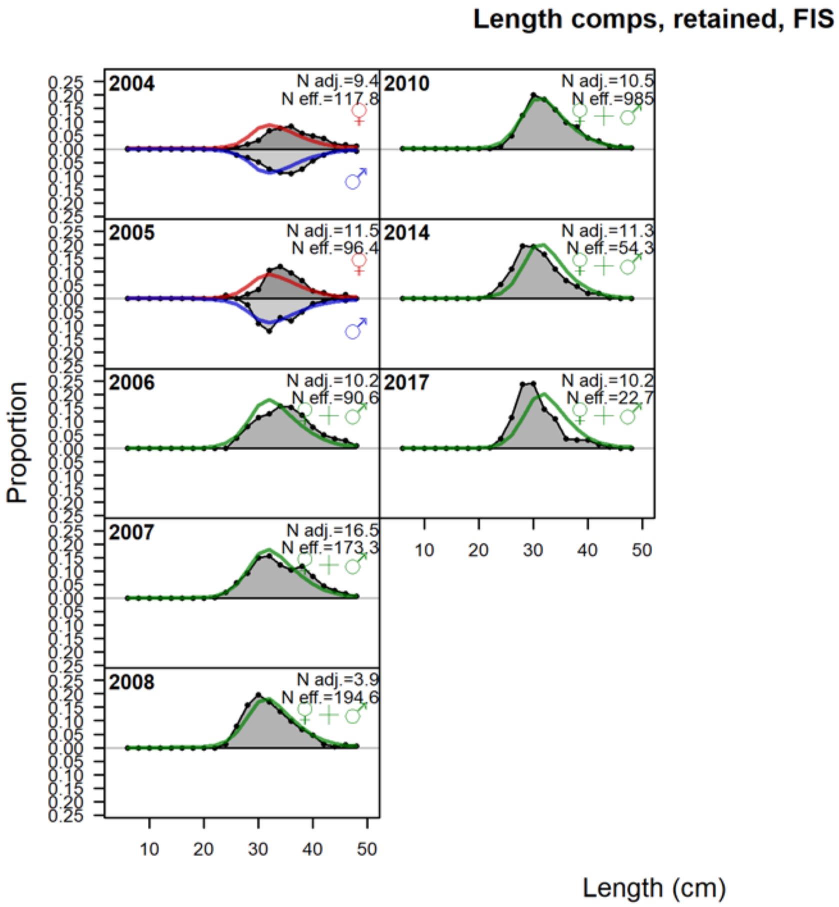

Figure A 10.2. Length composition fits - FIS retained.

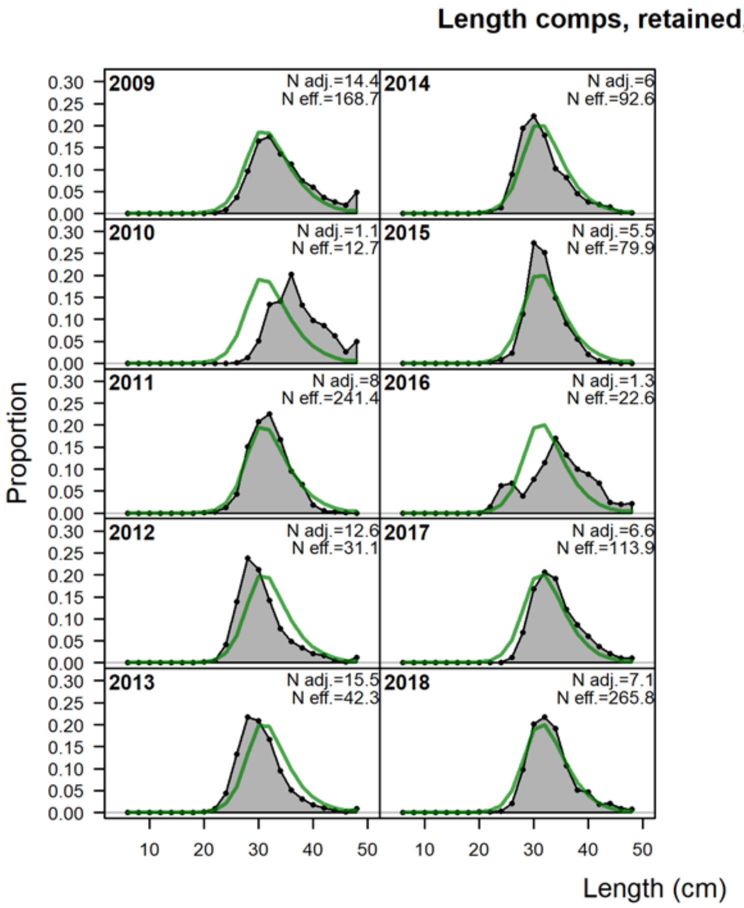

Figure A 10.3. Length composition fits - Industry.

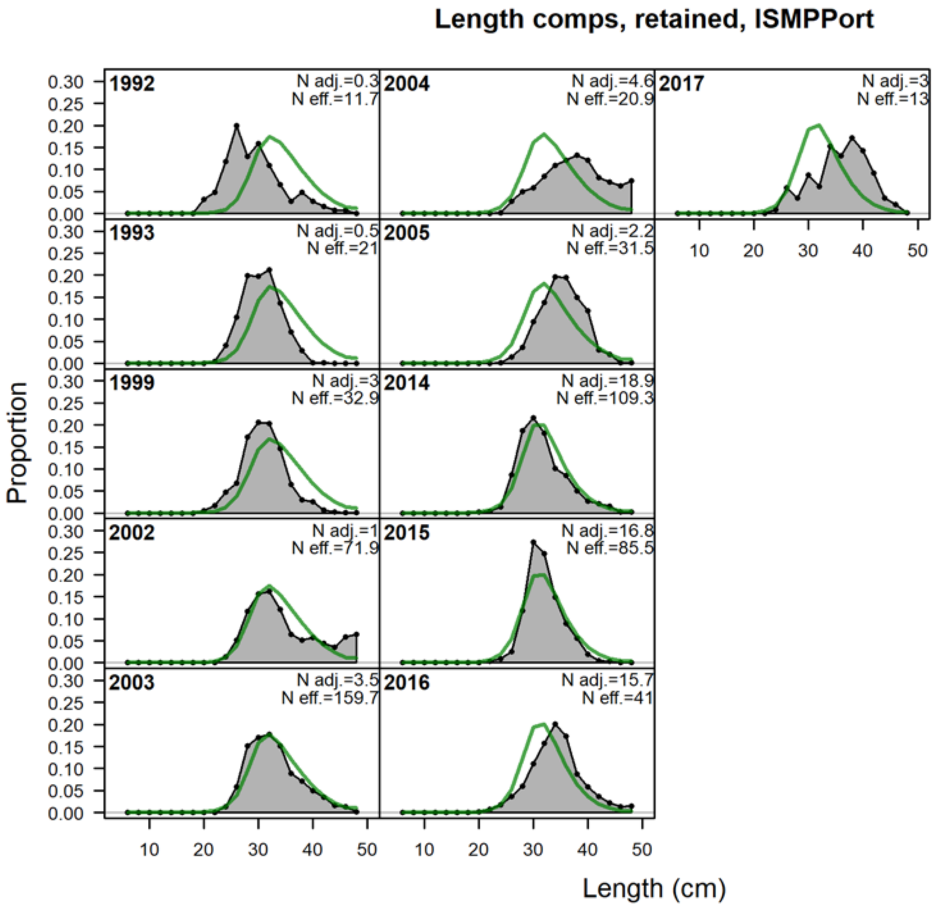

Figure A 10.4. Port length composition fits – ISMP.

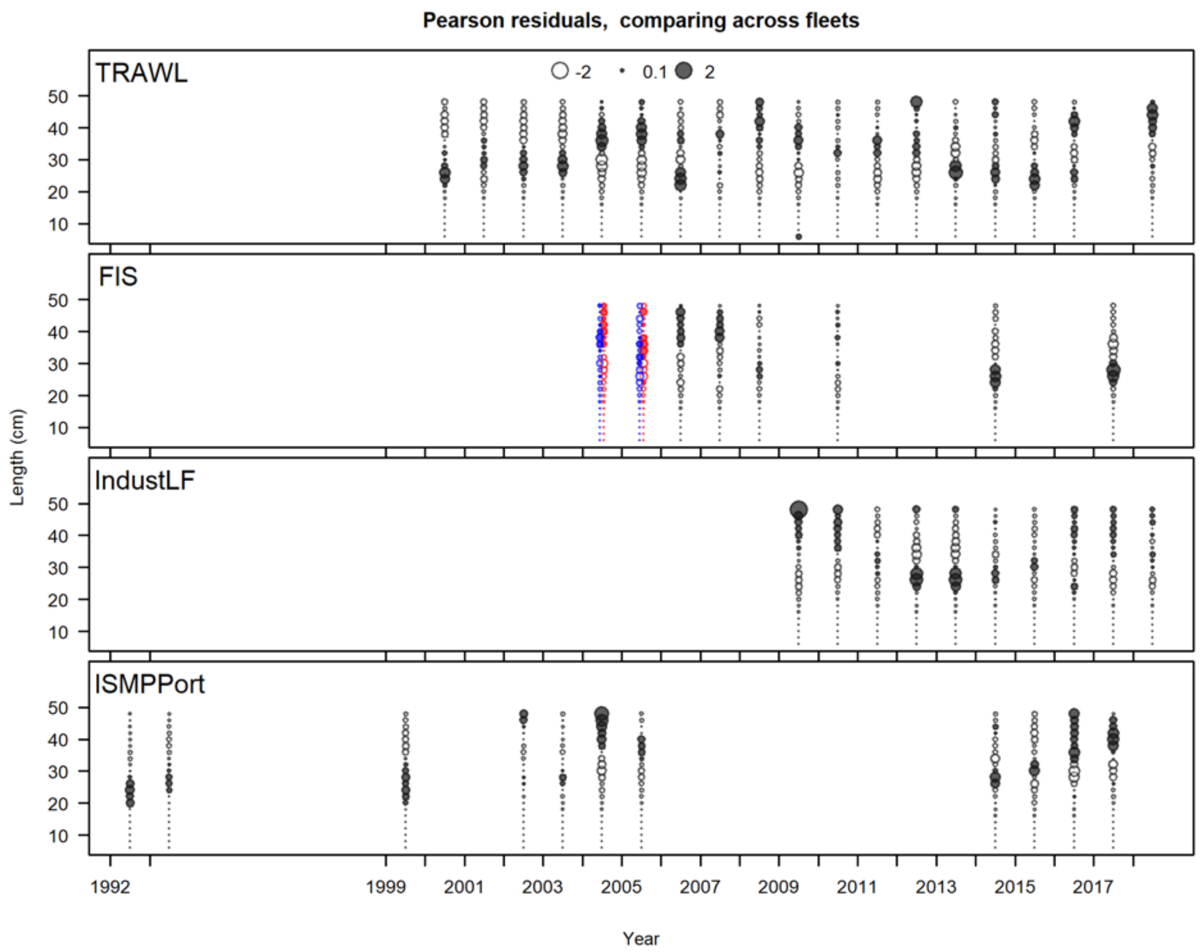

Figure A 10.5. Residuals from the annual length compositions (retained) displayed by year and sub-fleet.

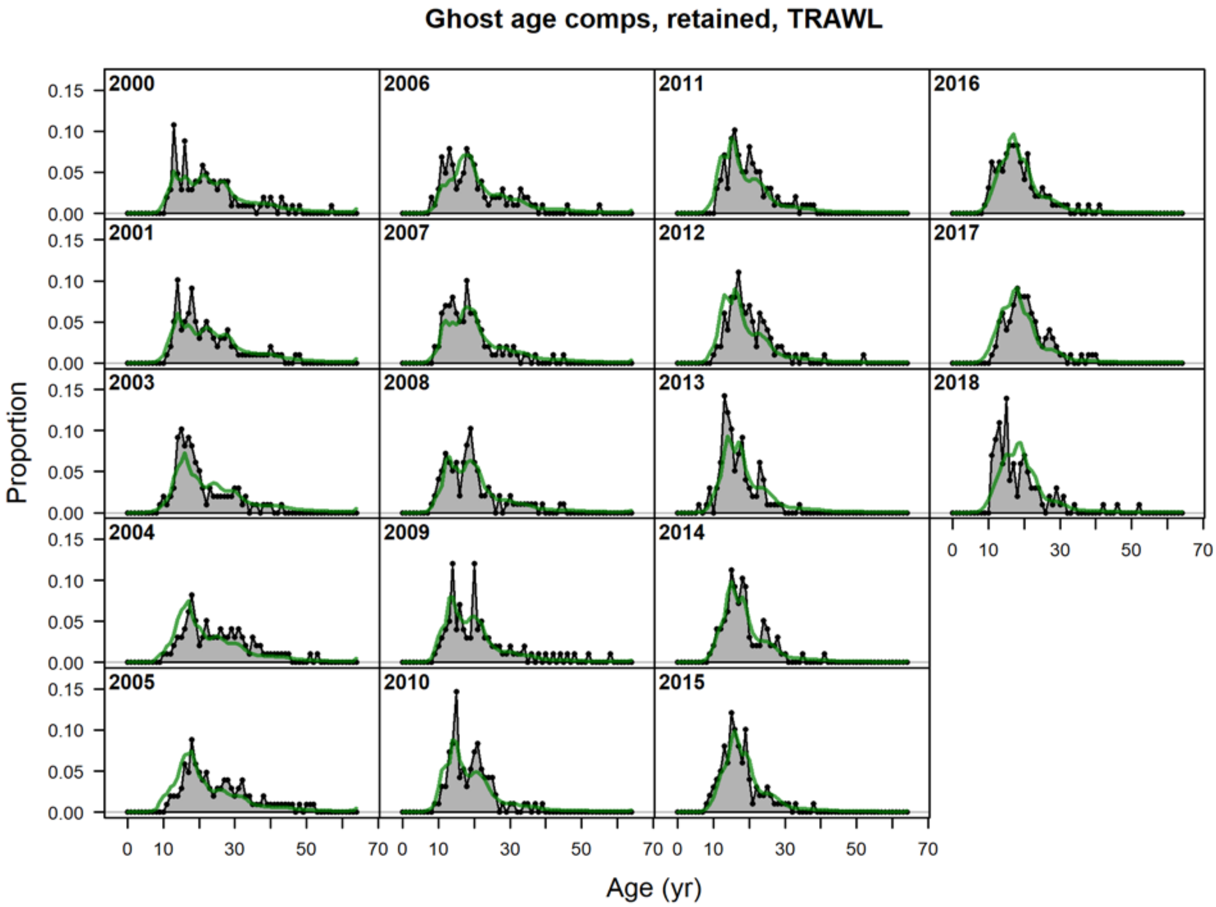

Figure A 10.6. Implied fits to age - Trawl onboard (retained).

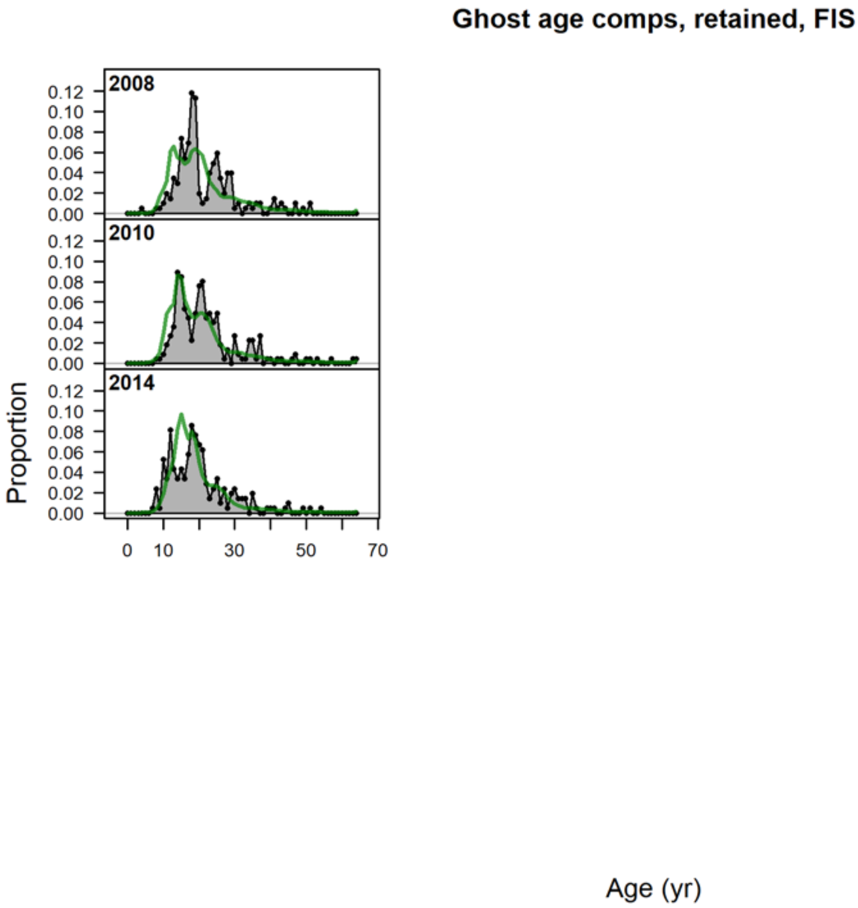

Figure A 10.7. Implied fits to age: GAB-FIS (retained).

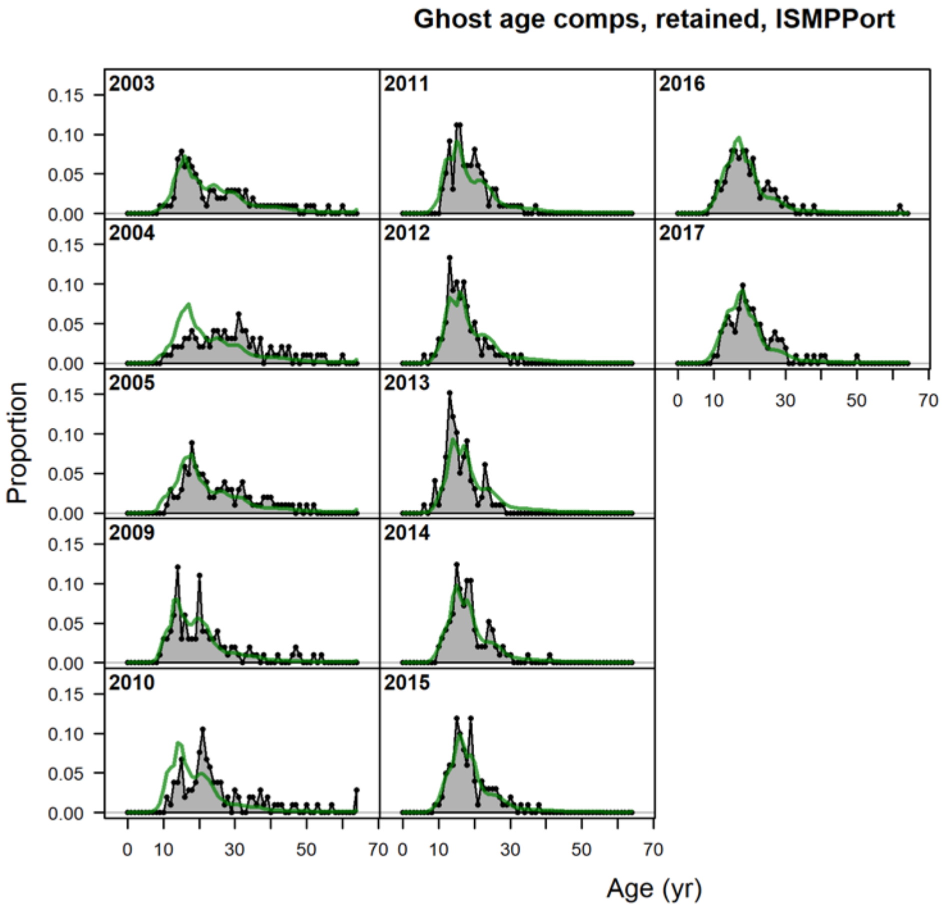

Figure A 10.8. Implied fits to age - ISMP Port.