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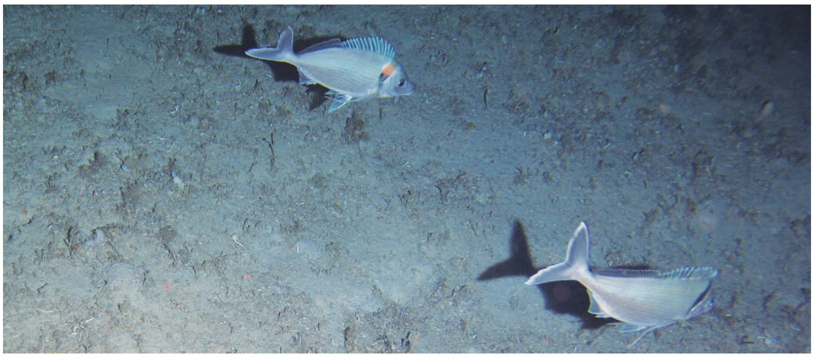
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2015



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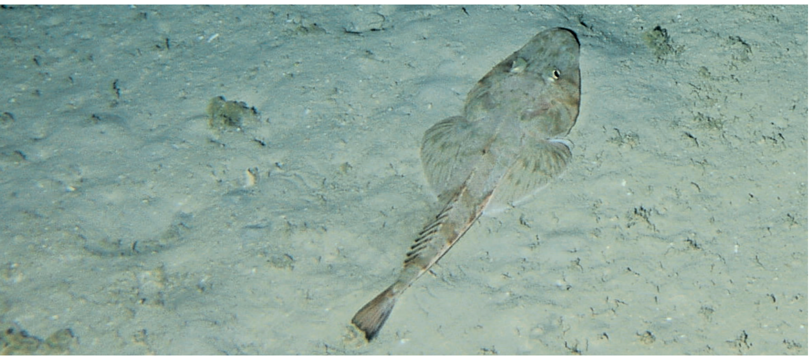

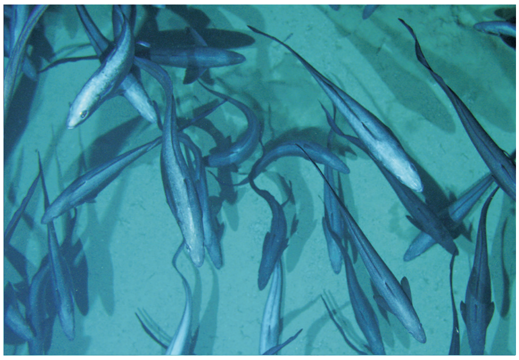

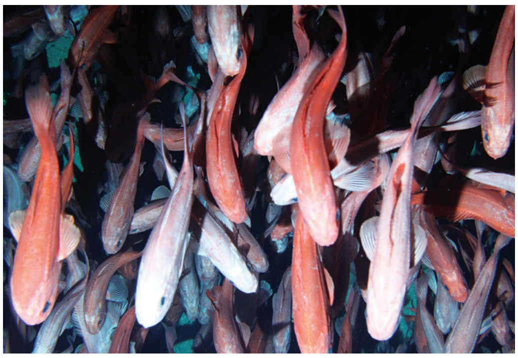

Principal investigator **G.N. Tuck**

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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 2015. 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 2015.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2015

Part 1: Tier 1 assessments

G.N. Tuck
June 2016
Report 2014/0818

Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2015 Part 1

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5. Bight redfish (*Centroberyx gerrardi*) stock assessment using data to 2014/2015

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5.1 Summary

This chapter updates the 2011 assessment of Bight redfish (*Centroberyx gerrardi*) to provide estimates of stock status in the Great Australian Bight at the start of 2015/16 (end of 2014/2015). This assessment was performed using the stock assessment package Stock Synthesis (v3.24u) and included data from AFMA log-books, the ISMP sampling program, the ageing facility, and from Industry sampling programs.

The base-case assessment estimates that the female spawning stock biomass at the start of 2015/2016 was 63% of unexploited female spawning stock biomass (SSB_0). The 2016/2017 recommended biological catch (RBC) under the agreed 20:35:41 harvest control rule is 862 t and the long-term yield (assuming average recruitment in the future) is 537 t. Averaging the RBC over the three year period 2016/2017 – 2018/2019, generates a three year RBC of 828 t and over the five year period 2016/2017 – 2020/2021, the average RBC would be 797 t. The reduction reflects the gradually declining RBC predicted when projecting the assessment model to a depletion level of 41%B_0. Lower RBCs are generated using a 20:35:48 harvest control rule.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can lead to the acoustic biomass estimate differing from the biomass available to survey on average. Informative prior distributions were developed for the catchability coefficient for the acoustic surveys, and the Francis (2011) data weighting method was applied to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices when the model was fitted. The other new data inputs were a revised egg survey estimate, a catchability coefficient for that survey, and an updated ageing error matrix using data from a recent re-ageing experiment (by Fish Ageing Services). The re-ageing experiment, which was designed to investigate between-year bias in age reads, found no evidence of a major bias in the early age readings for Eastern Zone orange roughy.

The unexploited female spawning biomass was estimated as 5,451 t, with a total unfished equilibrium exploitable biomass of 16,042 t. This major reduction in the estimate from that made in 2012 reflects the fact that the data now available are more informative about the unfished biomass and stock status.

Exploration of model sensitivity showed a variation in spawning biomass of between 57% and 69% of SSB_0, with this uncertainty largely driven by uncertainty over the estimate of natural mortality and size at maturity. These results are less uncertain than the previous assessments but now that the fisheries data are finally being informative about the state of the stock it remains possible that further data may enable the assessment to stabilize the RBC estimates between assessments.

5.2 Introduction

5.2.1 The Fishery

The trawl fishery in the GAB primarily targets two species, Bight redfish (*Centroberyx gerrardi*) and deepwater flathead (*Neoplatycephalus conatus*), and these have been fished sporadically in the Great Australian Bight (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 10m to 500m. Deepwater flathead are also endemic to Australia and inhabit waters from NW Tasmania, west to north of Geraldton in WA in depths from 70m to more than 490m (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.

5.2.2 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 32,000t and 12,000t 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 – 13,266t). In 2002 an updated assessment was carried out for Bight redfish and the unexploited biomass estimates for the base case model was then 9,563t (8,368 – 10,759).

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 13,932t 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 SS2 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 18,685t.

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 - SS3. 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 12,272t and the depletion at 77%.

Finally, in 2011, the Bight redfish assessment was updated using the latest version of SS3 (SS3.21d) and the latest 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% (Table 5.1).

Table 5.1. A summary of previous stock assessment outcomes for Bight redfish. The year of assessment usually relates to the final year of data collection, which is the fishing year involved (thus, 2011 is for the year 2010/2011). B0 is the unfished female spawning biomass. The yield is the RBC for the following year with the long term estimated sustainable yield in brackets for some years. The 1999 biomass estimate is of exploitable biomass while the rest reflect female spawning biomass.

Year	Authors	B0 (t)	Depletion	Yield (t) RBC
1999	Tilzey and Wise(1999)	~12000	-	200 - 400
2000	Wise and Tilzey(2000)	9095		
2002	Wise and Tilzey	9563		
2005	Wise and Klaer (2006)	12323	>79%	
2005	Klaer (2006)	24282		
2006	Klaer and Day (2007)	31660	94	4040 ()
2007	Klaer (2007)	18685	82	1524 ()
2009	Klaer (2010)	12272	77	1653 (948)
2011	Klaer (2012b)	26210	90	4407 (2143)

5.2.3 *Modifications to the Previous Assessment*

An initial base case was developed and presented to the GAB RAB in October 2015; this was used to describe the changes wrought on the previous assessment by the sequential addition of the new data now available along with other minor structural changes.

The latest version of the SS3 software was applied (SS3.24u; Methot and Wetzel, 2013) and then an array of data updates were applied, including some data streams that had not been used previously. The estimate of unfished female spawning biomass was greatly changed so a number of extra steps were included to ensure the changes were only due to the addition of new data.

The changes are described in a set different manipulations and changes to the old assessment:

1. Repeat the assessment from 2011 using the new software version SS3.24u
2. Use the older version of SS3 (SS3.24f) to test the effect of using new software.
3. Add catch and commercial CPUE to 2014/15.

4. Add survey abundance estimates to 2014/15.
5. Add length composition data from 2011/12 to 2014/15; a new step this year was to keep the port and on-board ISMP data separate. In addition, length composition data from all surveys were included and, again new this year, the on-board length composition data obtained through crew sampling from 2010/2011 – 2014/2015 were also included.
6. Estimate the selectivity curve for the Fishery Independent Survey.
7. Add age composition data from 2011/12 to 2014/15.
8. Add the ageing error matrix.
9. Estimate L_{min} (a growth curve parameter).
10. Again use the older version of SS3 (SS3.24f) to test the effect of using new software.
11. New to this assessment, add the age composition data from the FIS for the years 2008/2009, 2010/2011, and 2014/2015, in which it is available.
12. Use variance estimates around the recruitment deviates to set the last estimated recruitment to 2004/2005. Accept fitted recruitment deviation bias adjustment values.
13. The variance of the different length and age composition data and the CPUE data were balanced to generate the initial base case. The balancing procedure this year attempts to apply more emphasis to the CPUE time series. The model balancing also involved increasing the recruitment variation from 0.2 to 0.34 as further bias adjustments were required after adjusting the variance estimates on different data streams.

Once the base case was completed its dynamics were projected forwards for 40 years to estimate the long term RBC that would, at equilibrium, keep the stock to the MEY proxy target of 41%B_0 (Kompas *et al*., 2011).

Following the projections, 18 sensitivity analyses were conducted to provide a test of the structural assumptions made in the formulation of the assessment model. Likelihood profiles were also produced for natural mortality and for the size at 50% maturity.

5.3 Methods

5.3.1 The Data and Model Inputs

5.3.1.1 Biological Parameters

Male and female Bight redfish are assumed to have the same biological parameters except for the length-weight relationship (Table 5.2).

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; the model outcomes are so sensitive to this parameter that a likelihood profile, 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 other model outputs was conducted.

Maturity is modelled as a logistic function, with 50% maturity at 25 cm. Changing the size at maturity has almost no effect on the quality of the model fit but has a large effect on the estimates of stock biomass and status so a likelihood profile of size-at-maturity was also conducted. 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.

Table 5.2. Summary of selected parameters from the base case model. Sources: (1) Analyses of biological samples collected during the 2004 GAB reproductive study (Brown and Sivakumaran, 2007), (2) length and age samples collected between 2000-2003 and (3) length samples collected during the 2001 FRDC project

Description	Source	Parameter	Combined Male/Female	
Years		y	1960-2014	
Recruitment Deviates		r	est 1960 - 2005	
Fleets			1 trawl only	
Discards			none significant, not Fitted	
Age classes		a	0-65 years	
Sex ratio		p_s	0.5 (1:1)	
Natural mortality		M	estimated (0.1) per year	
Steepness		h	0.75	
Recruitment variation		σ_r	0.35	
Female maturity	1		25 cm (SL)	
Growth	2	L_{max}	37.939 cm (SL)	
		K	fitted	
		L_{min}	fitted	
		CV	fitted	
			Female	Male
Length-weight (based	3	f_1	0.000128 cm (SL)/gm	0.000144
on standard length)		f_2	2.559	2.522

5.3.1.2 Available Data

An array of different data sources are available for the Bight redfish assessment including catch (landings plus discards), standardized commercial CPUE, an index of relative abundance from the Fishery Independent Survey (FIS), age composition data from the Integrated Scientific Monitoring Program (ISMP) and from the FIS, and length composition data from the ISMP (keeping port sampling separate from the on-board sampling), from the FIS, and from crew sampling from on-board (Figure 5.1). Age-at-length composition data for the fleet designated Trawl and the FIS were calculated from the available length compositions and conditional age-at-length data (age-length keys). These do not comprise additional data and are not included in the fitting of the model but are shown for information.

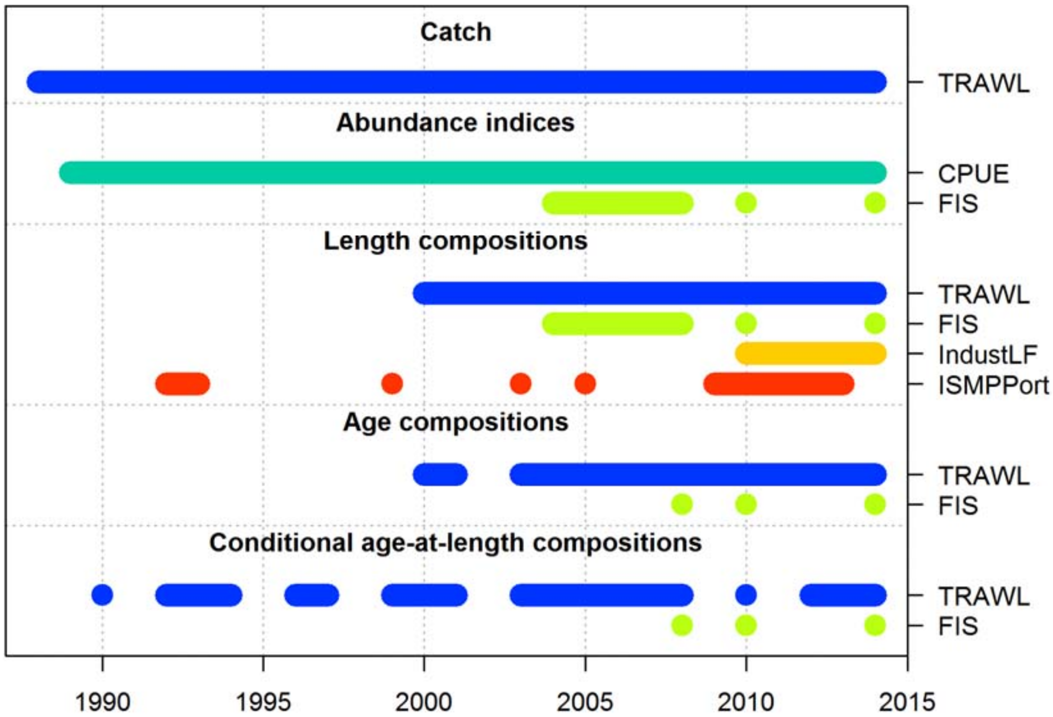

Figure 5.1. Data availability by type and year. The year axis denotes the first year of the financial year, thus 1995 = 1995/1996.

A landed catch history for Bight redfish is available for the years from 1988/1989 to 2014/2015 (Figure 5.2; Table 5.3). Landed catches were derived from GAB logbook records for the years to about 2000, 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 2006/2007 year (Table 5.3).

In order to calculate the Recommended Biological Catch (RBC) for 2016/2017, it is necessary to estimate the financial year catch for 2015/2016. TACs have been substantially under-caught in recent years and so the 2015/2016 catch was assumed to be the same as the catch in 2014/2015 - 238t.

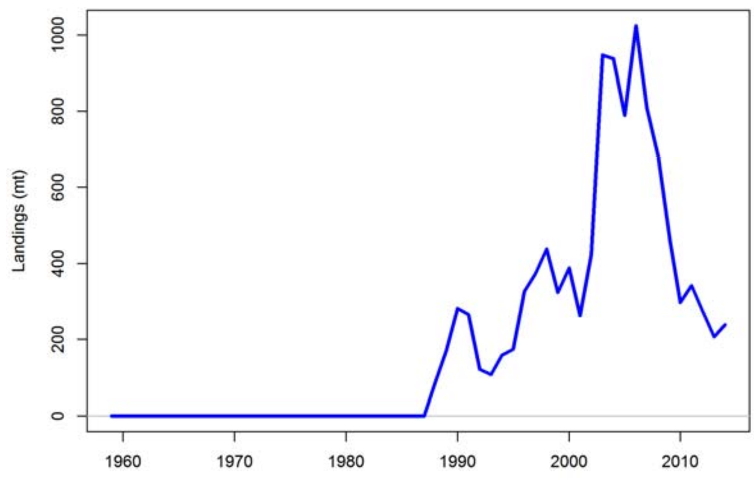

Figure 5.2. Total reported landed catch of Bight redfish 1987/1988 – 2014/2015 (see Table 5.3).

Table 5.3. Financial year values and estimates of total catch, standardized CPUE, the geometric mean CPUE, and number of vessels reporting Bight redfish in the GAB from 1988/1989 – 2014/2015. Discards are assumed to be trivial. Standardized CPUE is from Sporcic (2015).

Fishing Year	Catch	CPUE	Geometric Mean	Vessels
1988/1989	85.651			
1989/1990	170.833	1.744	31.605	7
1990/1991	281.808	1.580	36.646	8
1991/1992	265.612	1.507	27.318	8
1992/1993	120.698	1.144	18.338	3
1993/1994	107.472	1.046	16.240	5
1994/1995	157.803	0.724	11.724	6
1995/1996	173.922	0.860	11.802	5
1996/1997	327.177	0.969	15.335	6
1997/1998	372.617	1.039	16.023	7
1998/1999	437.788	1.204	20.206	7
1999/2000	323.641	1.077	17.185	7
2000/2001	387.879	0.925	15.649	5
2001/2002	262.613	0.675	10.857	5
2002/2003	424.672	0.742	13.466	8
2003/2004	946.477	1.087	20.110	10
2004/2005	937.456	1.010	18.368	9
2005/2006	789.704	0.972	17.406	10
2006/2007	1023.908	1.057	21.764	10
2007/2008	808.024	1.016	20.099	6
2008/2009	681.885	1.101	21.905	4
2009/2010	469.696	0.959	17.379	4
2010/2011	297.596	0.797	14.267	4
2011/2012	341.481	0.802	14.426	4
2012/2013	273.451	0.694	15.270	4
2013/2014	207.051	0.646	14.613	4
2014/2015	238.327	0.625	10.462	4

5.3.1.3 Catch Rate Indices

Previously, commercial catch rates have been standardised using Generalised Additive Models (GAMs) (Hobsbawn et al. 2002a, 2002b) and a log-linear model (Klaer, 2007). Standardisations for a range of SESSF species are carried out each year (see Haddon, 2014a,b; Sporcic, 2015) and Bight redfish is now included in the list of species analysed each year.

"Data from the GAB fishery used in the 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 that trawled for more than one hour but less than 10 hours. Instead of 5 degree zones across the GAB, 2.5 degree zones were employed to allow better resolution of location based differences in CPUE. An examination of the depth distribution of catches suggests that this could be modified to become 100 – 250 m with essentially no loss of information and the outcomes do not differ from the base case adopted here; All vessels and 0 – 1000 m). Catches in 1986/1987 were relatively low and only taken by a single vessel and so were omitted from analysis." (Sporcic, 2015, p209)

The point about the depth categories used is important, as the inclusion of relatively empty depth categories introduces more noise than information into an analysis (Table 5.4). It is recommended that the depth range used in the standardization should be reduced at least to 0 – 500m in future analyses.

Table 5.4. The number of records and catch reported by different depth categories. Approximately 3 t of catch has been reported from below 1000m across the duration of the fishery, and 6.381 t has been reported from depths greater than 500m.

50 m Depth Categories					25 m Depth Categories		
Depth	Records	Catch (t)	Percent	Cumulative%	Depth	Records	Catch (t)
0	107	2.584	0.025	0.025	0	93	2.295
50	4963	40.066	0.383	0.407	25	1515	10.788
100	11432	1444.128	13.790	14.197	50	3462	29.567
150	40580	8515.162	81.309	95.506	75	1898	37.178
200	2975	424.509	4.054	99.560	100	7246	1050.813
250	299	22.563	0.215	99.775	125	33298	7103.245
300	49	3.876	0.037	99.812	150	9570	1768.056
350	31	1.223	0.012	99.824	175	2162	357.659
400	28	0.746	0.007	99.831	200	777	65.668
450	17	3.269	0.031	99.862	225	210	10.168
500	15	5.044	0.048	99.911	250	125	13.577
550	16	2.012	0.019	99.930	275	32	1.939
600	9	1.378	0.013	99.943	300	17	1.937
650	7	1.556	0.015	99.958	325	17	0.418
700	1	0.040	0.000	99.958	350	14	0.805
750	3	0.480	0.005	99.963	375	18	0.295
800	1	0.020	0.000	99.963	400	10	0.451
850	1	0.010	0.000	99.963	425	9	0.971
900	3	0.355	0.003	99.966	450	8	2.298
950	2	0.500	0.005	99.971	475	5	0.613
1000	1	0.030	0.000	99.971	500	10	4.432

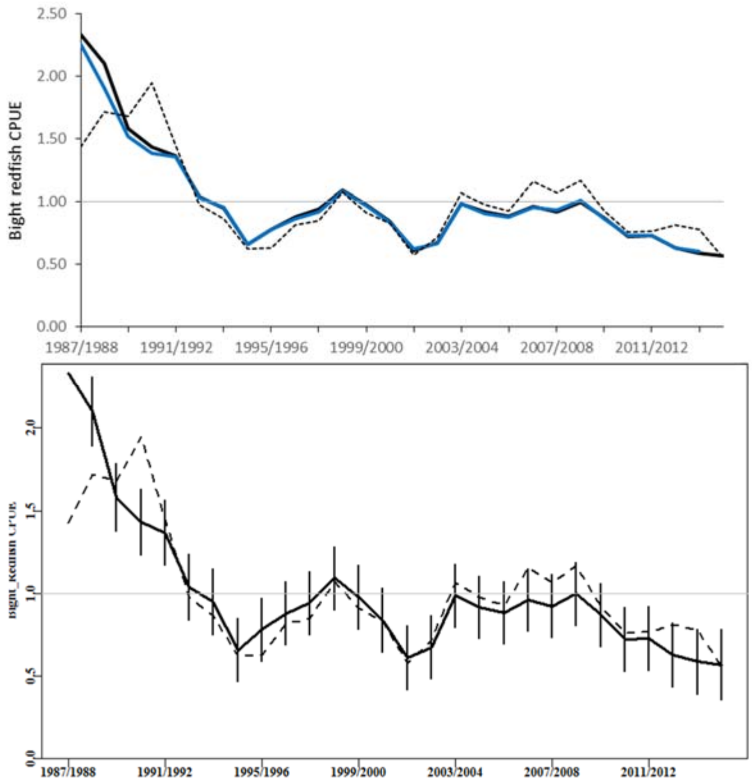

Figure 5.3. The standardized CPUE for Bight Redfish from the trawl fishery in the GAB (copied from Sporcic, 2015, p 212). Upper graph: solid black line the standardized catch rates (relative to the mean of the standardized catch rates). The blue line corresponds to last year's standardized catch rates. Lower graph: Standardized indices (solid black line), 95% CI (vertical lines) and geometric mean (dashed black line). This illustrates the impact on the relative uncertainty of the relatively small number of records, especially in the early years.

5.3.1.4 *Fishery Independent Survey Abundance Estimates*

There are now seven estimates of relative abundance from the FIS (Table 5.5; Knuckey, *et al*., 2015). The variation relative to the individual abundance estimates are used initially, but in the process of balancing the output variability with that input, these values were greatly expanded. These data were included in the assessment as they were previously (Klaer, 2012).

Table 5.5. FIS relative abundance estimates for Bight redfish, with each survey estimate's coefficient of variation.

Year	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2010/2011	2014/2015
Estimate	20887	25380	25713	14591	27610	13189	3633
CV	0.13	0.16	0.16	0.11	0.18	0.13	0.20

5.3.1.5 *Age Composition Data*

Previously (Klaer, 2012), age composition data from the ISMP sampling was mixed up with three years of FIS age data. In this current assessment the ISMP age composition data is included as previously but now the ageing data from three years of the FIS are included separately (2008/2009, 2010/2011, and 2014/2015).

The ISMP ageing data illustrates that since about 2006/2007 the proportion of older fish has declined (Table 5.4). While a comparison of the age composition seen in the FIS years and the ISMP samples from the same financial year (Figure 5.5) suggests similarities, although the progression of two modes of age classes appears clearer in the FIS data and, at least in the last two years of the FIS, there appear to be a higher proportion of older fish present in the FIS samples.

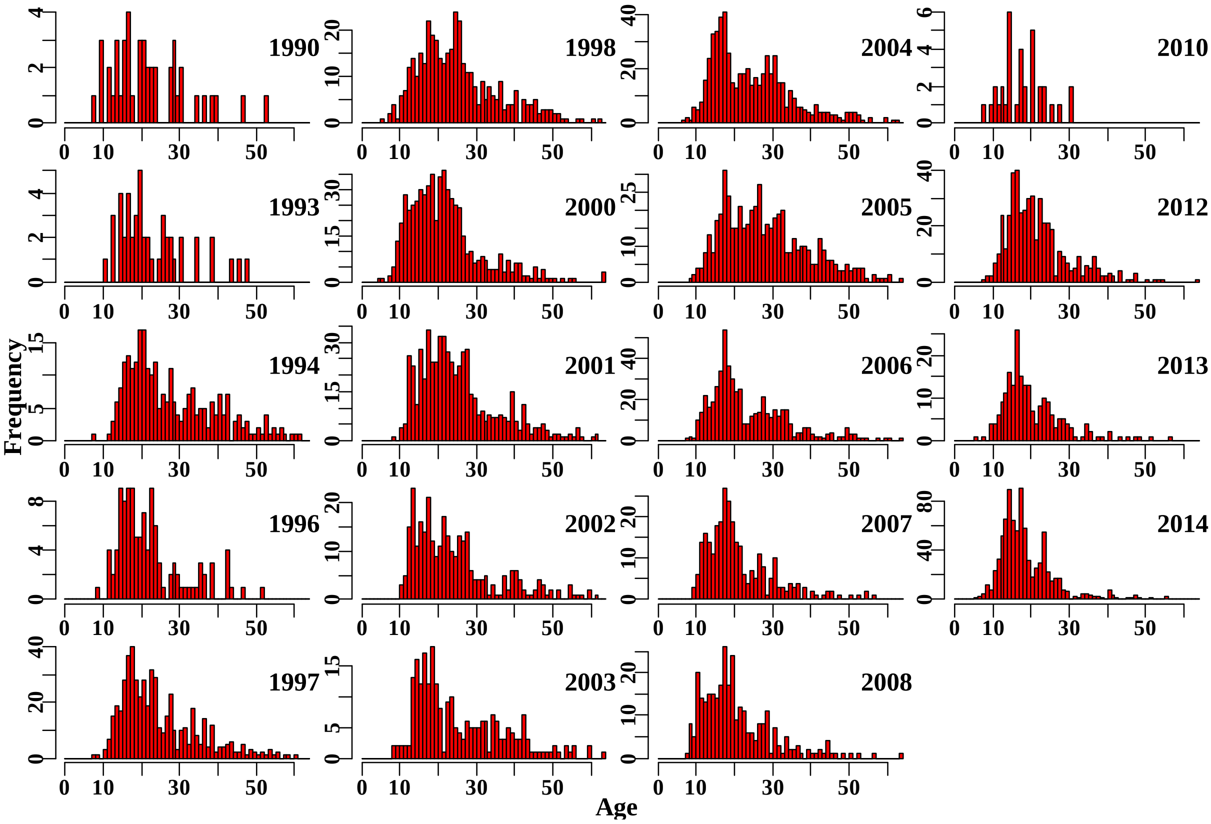

Figure 5.4. All ISMP ageing data used by year, illustrating the relative sample size and the relatively recent contraction in the older age classes. Each year label relates to the first year of the financial year; 2000 = 2000/2001.

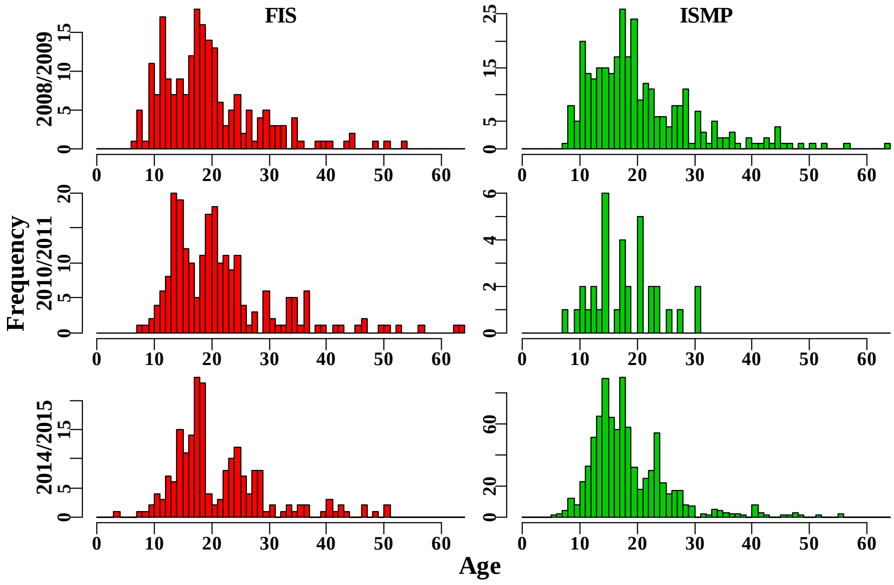

Figure 5.5. A comparison of the age composition of Bight redfish from the FIS and from the ISMP from the same financial years.

5.3.1.6 Length Composition Data

Previously (Klaer, 2012), only length composition data from the ISMP sampling were used, and port and on-board samples were considered together. In this current assessment the port and on-board ISMP length samples are kept separate, and there are further length composition data available from the FIS and from crew-member collected data (Figure 5.1).

The crew collected length composition data exhibited an unusual and atypical distribution in sample from 2009 and this was therefore omitted from consideration (Figure 5.6), however, the data from 2010/2011 to 2014/2015 were included using the same selectivity as for the ISMP data. Over a longer time frame the length composition data from the FIS also exhibits variation through time (Figure 5.7).

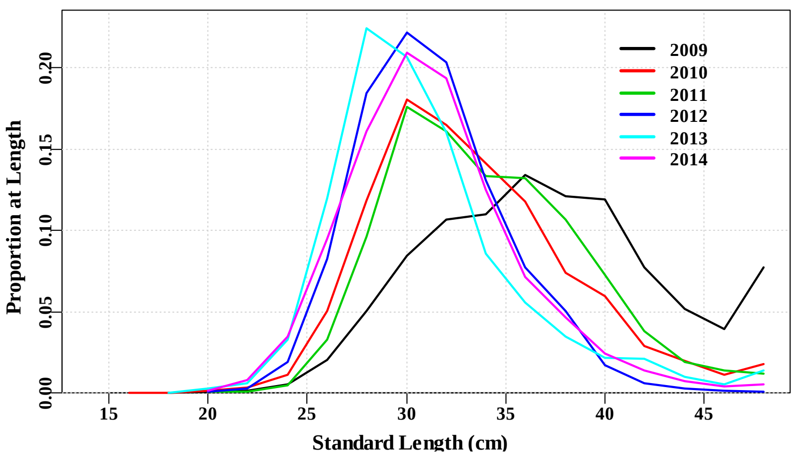

Figure 5.6. Length composition data obtained from crew sampling on-board. The data for 2009 was exceptional and constituted a relatively small sample and hence was omitted from consideration.

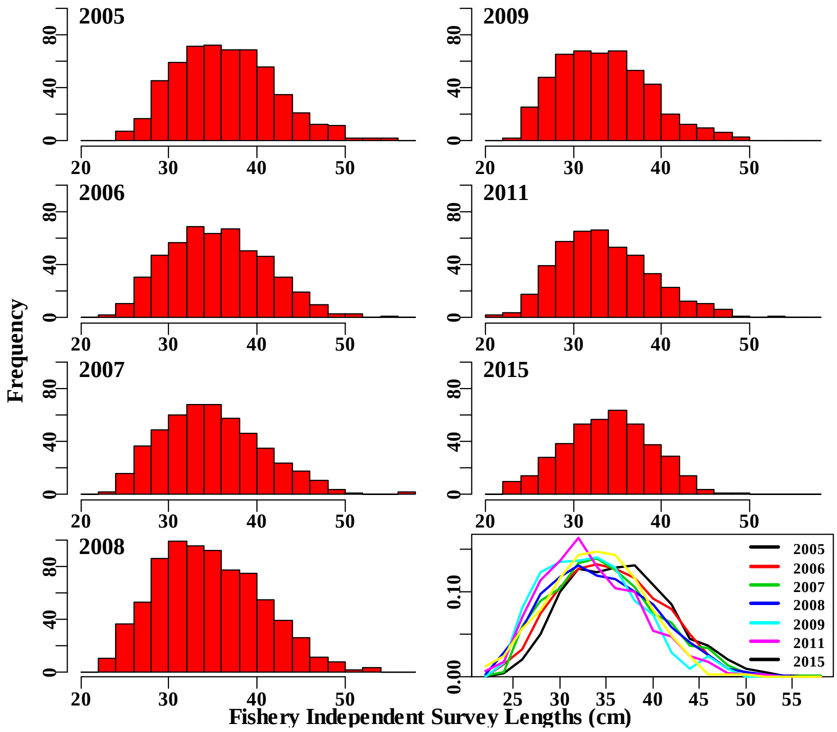

Figure 5.7. The length composition data from the seven FIS that have occurred in the GAB. The plot at bottom right illustrates the contrast between years.

The length composition data from the ISMP also varies considerably from year to year in both the on-board and port data (Figure 5.8, Figure 5.9).

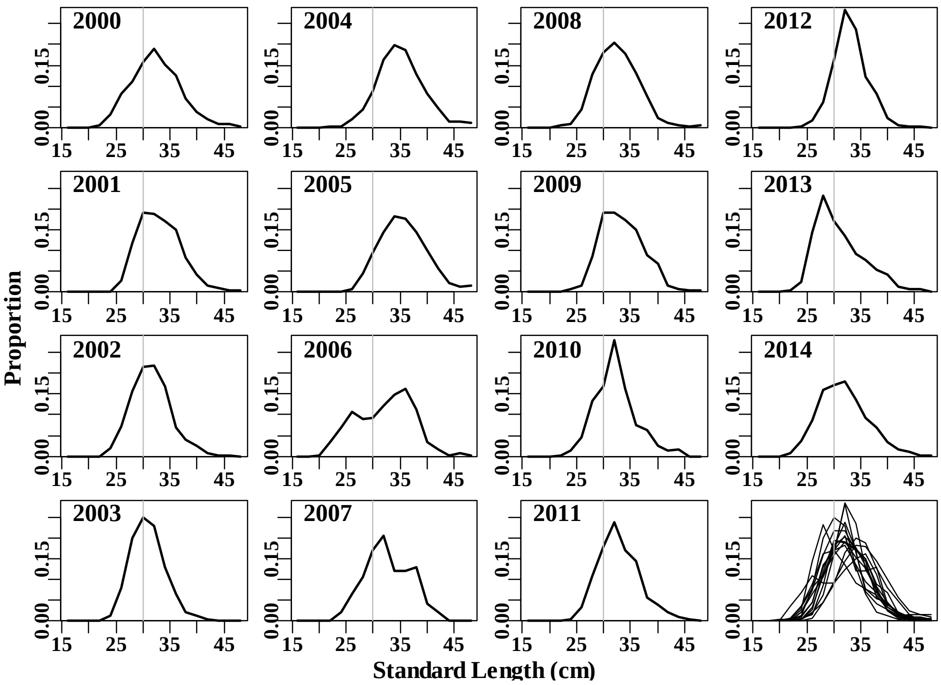

Figure 5.8. The proportional distribution of on-board length composition data for Bight redfish from the ISMP. The vertical grey line at 30cm is to ease visual comparisons. The plot at bottom right is a combination of all the plots to illustrate the variation between years.

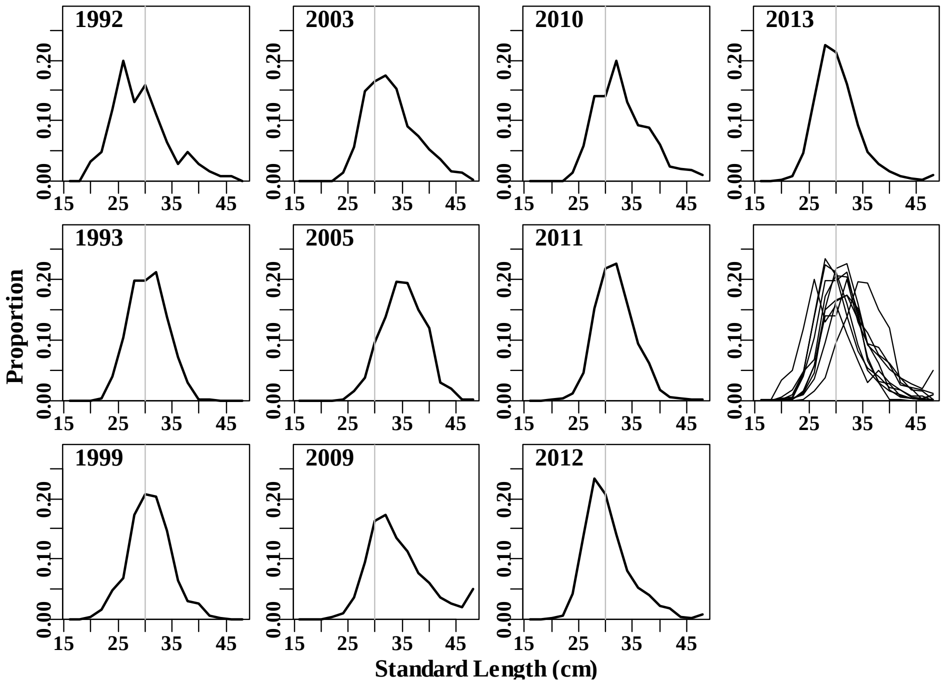

Figure 5.9. The proportional distribution of Port sampled length composition data for Bight redfish from the ISMP. The vertical grey line at 30cm is to ease visual comparisons. The plot at bottom right is a combination of all the plots to illustrate the variation between years.

Table 5.6. Original sample sizes for the length and age composition data for Bight redfish.

Financial Year	ISMP Port LF	ISMP on-Board LF	Industry LF	FIS LF	ISMP Ages	FIS Ages
1992/1993	246					
1993/1994	516					
1999/2000	5324					
2000/2001		3440			630	
2001/2002		2618			474	
2002/2003		1173				
2003/2004	2706	1511			602	
2004/2005		3362		550	571	
2005/2006	541	2271		512	566	
2006/2007		781		499	481	
2007/2008		141		763	443	
2008/2009		716		489	561	202
2009/2010	978	2089			668	
2010/2011	179	217	11033	439	371	223
2011/2012	1652	2167	7443		337	
2012/2013	1873	577	8488		490	
2013/2014	182	1147	10105		334	
2014/2015		1518	5143	405	712	208

5.3.1.7 Age-Reading Error

The age estimates are assumed to be unbiased but subject to random age-reading errors (Punt et al., 2008). Standard deviations for aging error by reader have been estimated, producing the age-reading error matrix (A.E. Punt, pers. comm.). Selectivity is low for ages below 10.

Table 5.7. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes.

Age	StDev.	Age	StDev.	Age	StDev.	Age	StDev.
0	0.0066	11	0.8096	22	0.8422	33	0.8432
1	0.0066	12	0.8188	23	0.8425	34	0.8432
2	0.2365	13	0.8255	24	0.8427	35	0.8432
3	0.4033	14	0.8304	25	0.8428	36	0.8432
4	0.5242	15	0.8339	26	0.8429	37	0.8432
5	0.6119	16	0.8365	27	0.8430	38	0.8432
6	0.6754	17	0.8383	28	0.8431	39	0.8432
7	0.7215	18	0.8397	29	0.8431	40	0.8432
8	0.7550	19	0.8406	30	0.8431	41	0.8432
9	0.7792	20	0.8413	31	0.8432	42	0.8432
10	0.7968	21	0.8419	32	0.8432	43 - 65	0.8432

5.3.2 ***Stock Assessment***

5.3.2.1 Population Dynamics Model and Parameter Estimation

A two-sex stock assessment for Bight redfish has been implemented using the software package Stock Synthesis (SS, version 3.24u; Methot and Wetzel, 2013). SS is a statistical age- and length-structured model that can be used to fit the various data streams now available for Bight redfish, simultaneously. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS operating manual (Methot, 2015) and technical description (Methot and Wetzel, 2013) and are not reproduced here.

A single stock of Bight redfish was assumed to occur across the GAB. The stock was assumed to have been unexploited prior to 1988/1989, although minor catches have been recorded back to 1986/1987. The input CVs of the catch rate index and the biomass survey were initially set to fixed values which are effectively arbitrary in the final phase of the model fitting. These values are revised using an iterative process to reweight the variances of the different data streams once parameter estimates have been obtained. Within each abundance index, the variation of all of the annual estimates is assumed to be equal.

The selectivity pattern for the trawl fleet was modelled as not changing through time. The two parameters of the selectivity function were estimated within the assessment. A separate selectivity was estimated for the FIS, and now that FIS length and age composition data are included as data streams this selectivity was found to differ from the rest of the trawl fishery.

The rate of natural mortality, M, was assumed to be constant with age, and also constant through time. The natural mortality rate is estimated in the base-case analysis.

Recruitment was assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis was assumed to be 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment deviations) were estimated from 1959/1960 to 2004/2005. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was set equal to 0.2 to begin with, which is low relative to many other species, however, after balancing and recruitment deviate bias adjustment (Methot and Taylor, 2011) it ended at 0.335, which remains relatively low. The recruitment deviates for more recent years cannot be estimated well because it can take 10 or more years for larval fish to grow and then enter the fishery. Hence, it can take 10 years before information about relative recruitment levels becomes available to the model.

Age 65 is treated as a plus group into which all animals predicted to survive to ages greater than 65 are accumulated. Growth of Bight redfish was also 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 being determined from the fitting of the growth curve within the assessment using the age-at-length data. The potential for age-reading errors (Punt *et al*., 2008) is accounted for within the model by the inclusion of an age-reading error matrix (Table 5.7). The only difference in growth by sex was the length-weight relationship.

5.3.2.2 Relative Data Weighting

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. Most of the indices (CPUE, composition data) used in fisheries underestimate their true variance by only reporting measurement and not process error.

Sample sizes for length frequency data, this year, were the number of shots from which measurements were made rather than the absolute number of measurements obtained. The reason is that a set of observations from any particular shot or landing will tend to be correlated such that individuals within a sample are more likely to be similar than individuals between samples, so that true variation is underestimated. This is the reason why, to obtain a more representative sample of a population, it is generally better to take relatively small samples from many different landings than large samples from just a few landings. Treating each shot as a single sample is a better approximation to the effective sample size that simply counting each measurement as an independent observation.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size was equal to the effective sample size calculated by the model.

The tuning procedure now used (Andre Punt pers comm.; after Day *et al.* 2015) was to:

1. Set the CV for the commercial CPUE value 0.2 for all years (set those for the FIS to the estimated CVs) (this relatively low value is used to encourage a good fit to the abundance data).
2. Simultaneously tune the sample size multipliers for the length frequencies and ages using Francis weights for the LFs and Francis B (the larger of the Francis A and B factors, Francis 2011). Iterate to convergence.
3. Adjust the recruitment variance (σ_r) by replacing it with the RMSE and iterating to convergence (keep altering the recruitment bias adjustment ramps at the same time).

4. Weight the commercial CPUE and FIS abundance indices by replacing these with the relevant variance adjustment factors. Iterate to convergence.
5. Reweight the age data using the Francis A adjustment factor, just once (no iterating).
6. Repeat steps 3 and 4.

This procedure may change in the future. For example, it was found that adjusting all of these variance adjustments and the bias adjustment on the recruitment all at the same time led to the same outcomes as doing the process sequentially (at least for the Bight redfish assessment).

5.3.2.3 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith *et al.*2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system for fishing years 2006-2015. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Within the SESSF tier system (Smith et al., 2014) 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 be used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. 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 as a basis for using a 20:35:41 rule for Bight redfish (Kompas et al., 2012).

Estimating the following year's RBC entails calculating the catch that would be equivalent to a fishing mortality that would, at equilibrium, give rise to a spawning biomass depletion level of 41%B_0. Estimating the long term RBC entails projecting the stock assessment forward imposing catches calculated using the Tier 1 harvest control rule (Day, 2009) until the target of 41%B_0 is achieved and citing that final catch level.

5.3.2.4 The Development of the Base-Case Assessment

Fourteen sequential changes were made to the 2011 assessment (Table 5.8). Some had only very minor effects, others had much larger effects. While it was possible to closely match the original assessment spawning biomass time-series (Klaer, 2012b) using the SS3.24f version the outcome, in terms of absolute spawning biomass, changes dramatically when no new data were included and the only change made was to use the latest version of SS3 (SS3.24u). This could have been because the earlier data was uninformative about the spawning biomass levels or because there was a flaw in the software. Other assessments using similarly changed SS3 versions have been conducted this year (Jackass Morwong, Tuck *et al*, 2015; Silver Warehou; Day *et al*, 2015), where such differences did not occur. A further test was made by applying the older SS3 version (SS3.24f) to the scenario after all the age related changes had been made (Age2015_24f). The fact that no discernible differences were seen between the dynamics expressed by that scenario and that expressed by the Age2015 scenario (combined with the ageing error and estLmin scenarios) demonstrate that the differences in the earlier comparison were due to the data being unable to estimate the starting unfished biomass (B_0) with any precision rather than a flaw in the software.

Table 5.8. The thirteen sequential changes made to the 2011 assessment model. Further results for the ageing error matrix and for the re-estimation of the lower growth curve parameters will not be included as these were almost indistinguishable from the outcome of the Age2015 addition. The final base-case is the balanced model.

Index	Name	Description
1	Klaer2011	The spawning biomass estimates from Klaer (2012a)
2	origbase24f	Application of the previous version of SS3 - SS3.24f
3	origbase	Application of the current version of SS3 - SS3.24u
4	CatCE2015	Inclusion of the new catch and CPUE from the fishery
5	Surv2015	Inclusion of the new relative abundance index from the FIS
6	Len2015	Inclusion of new length frequency information; ISMP, FIS, Industry
7	FISsel	Check the need for a separate selectivity curve for the FIS
8	Age2015	Add the new ISMP ageing data
9	ageingerror	Include new ageing error matrix
10	estLmin	re-estimate the lower growth curve parameter
11	Age2015_24f	A repeat of the Age2015 (with the addition of ageing error and estimate of Lmin, but using the older version of SS3.
12	AgeFIS	Include the ageing data from the FIS: 2009, 2011, and 2015
13	Rlast98	Estimate more recent recruitment deviates
14	Balanced	iteratively balance the variance across the various data streams and adjustment the recruitment levels and bias adjustment

5.3.2.5 *Sensitivity Tests*

A number of tests were used to examine the sensitivity of the results of the model to some of the assumptions and data inputs (Table 5.9). Model outcomes were sensitive to the value of natural mortality, so a further likelihood profile (Venzon and Moolgarkar, 1988) was made for that parameter.

Table 5.9. Changes used to test the model's sensitivity to modified assumptions and data inputs.

1. M = 0.075 yr^{-1}. (relative to the base-case model estimate of 0.1077)
2. M = 0.977 yr^{-1} (because the effect of M = 0.075 was very
3. M = 0.125 yr^{-1}.
4. 50% maturity at 23cm.
5. 50% maturity at 27 cm.
6. σ_R set to 0.235
7. σ_R set to 0.435
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 abundance (CPUE) data.
13. Halve the weighting on the abundance (CPUE) data.
14. Derive the RBC using the 20:35:48 harvest control rule.
15. Fix steepness (h) at 0.65
16. Fix steepness (h) at 0.85
17. No Survey Data (remove index, age- and length-composition data)
18. Estimate Recruitment deviates 1960 – 2003

The results of the sensitivity tests are summarized by the effects on the absolute likelihoods associated with each data stream, the total likelihoods, which includes the effect of changes to the Lambdas or weights applied, and the following quantities (see Table 5.14):

1. SSB0: the average unexploited female spawning biomass.
2. SSB_{2014}: the female spawning biomass at the start of 2015/2016.
3. SSB_{2014}/SSB_0: female spawning biomass depletion at the start of 2015/2016
4. M: natural mortality
5. $RBC_{2016/2017}$

5.4 Results and Discussions

5.4.1 *The Base-Case Analysis*

Stepping sequentially through the different scenarios leading from the 2011 assessment to the current base-case the general result was that most scenarios, that had an observable influence on the outcome, led to declines in the estimated unfished spawning biomass. The exception was the final balancing of variances between the data streams and adjustment of the recruitment bias adjustment and variation of recruitment deviates, which increased current spawning biomass by about 25% from 2697 t to 3432 t (Table 5.10).The reduction in biomass from the earlier assessment implied that the catches that had been removed had imposed a higher fishing mortality rate than estimated previously so the final depletion level of 63%B_0 was closer to the target reference point of 41%B_0 (81% down to 63%B_0; Table 5.10).

Table 5.10. The spawning biomass at the end of 2014/2015, with the 2014 depletion obtained during the development of the 2015 variance balanced base-case assessment for Bight redfish.

Scenario	B_0	2014SpB	2014StDev	Depletion	2014CV
origbase24f	21182.2	17124.9	12320.5	0.808	0.719
origbase	12659.3	9790.7	3713.8	0.773	0.379
CatCE2015	8980.0	6624.8	1492.1	0.738	0.225
Surv2015	8976.6	6586.8	1322.0	0.734	0.201
Len2015	7573.0	5196.3	978.3	0.686	0.188
FISsel	7317.4	4948.7	917.6	0.676	0.185
Age2015	5707.7	3627.6	415.0	0.636	0.114
Age2015_24	5819.6	3731.8	436.0	0.641	0.117
AgeFIS	4850.0	2654.8	161.1	0.547	0.061
Rlast03	4895.1	2697.9	238.8	0.551	0.089
Base-Case	**5451.0**	**3436.8**	**421.9**	**0.630**	**0.123**

5.4.1.1 Comparison of the Outcomes from Different Scenarios

To examine the effect of each data component on the model output the predicted female spawning biomass, as both biomass (t) and depletion were plotted, each on the same scale (Figure 5.10) to enable simple visual comparisons between scenarios. Using SS3.24f instead of SS3.21d, as used by Klaer, 2012a), led to a minor change in the unfished biomass (*B_0*) but the time-series of depletion levels were effectively identical with the lines for 'Klaer2011' and 'origbase24f' lying on top of each other. Similarly, AgeFIS and Rlast03 also lie on top of each other with only minor variations (Figure 5.10). The use of the more recent version of SS3 led immediately to reduced (improved) variation (a smaller CV), which continued to decline as more data and options were added (Table 5.10).

The relatively low catches in the most recent years have led to a degree of stock building since 2009/2010 or 2010/2011. This pattern of depletion and recovery suggests that the catch levels of ~800 – 1000 t are too high to be maintained for long periods but also that catches could be more than ~300 t and still be sustainable in the long term (Figure 5.10).

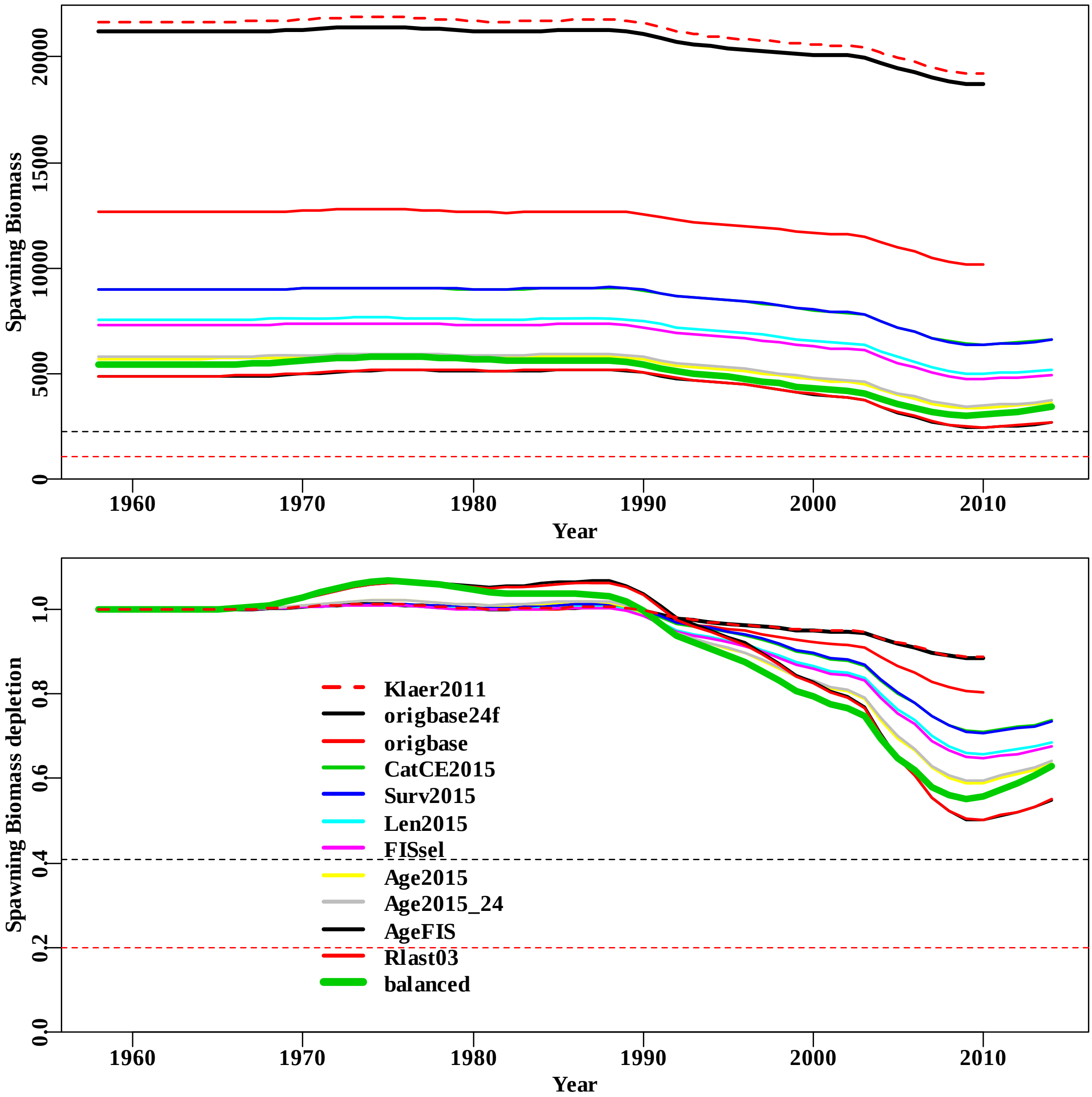

Figure 5.10. The predicted female spawning biomass and relative depletion level for the main scenarios describing the inclusion of different data and alternative assessment software. Some lines sit almost exactly on top of each other (for example the Age2015 and Age2015_24), the thicker green line is the balanced outcome from the base-case (see Table 5.8 for an explanation of each scenario).

5.4.2 *Model Fits*

The estimated growth curve for female and male Bight redfish is assumed to be the same (Figure 5.11). All growth parameters are estimated by the model except for L_{max} (Table 5.11).

With only a trawl fleet and Trawl run FIS, selectivity is assumed to be logistic. 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). A different selectivity was found to be required to appropriately describe the FIS length and age data (Figure 5.11; Table 5.11).

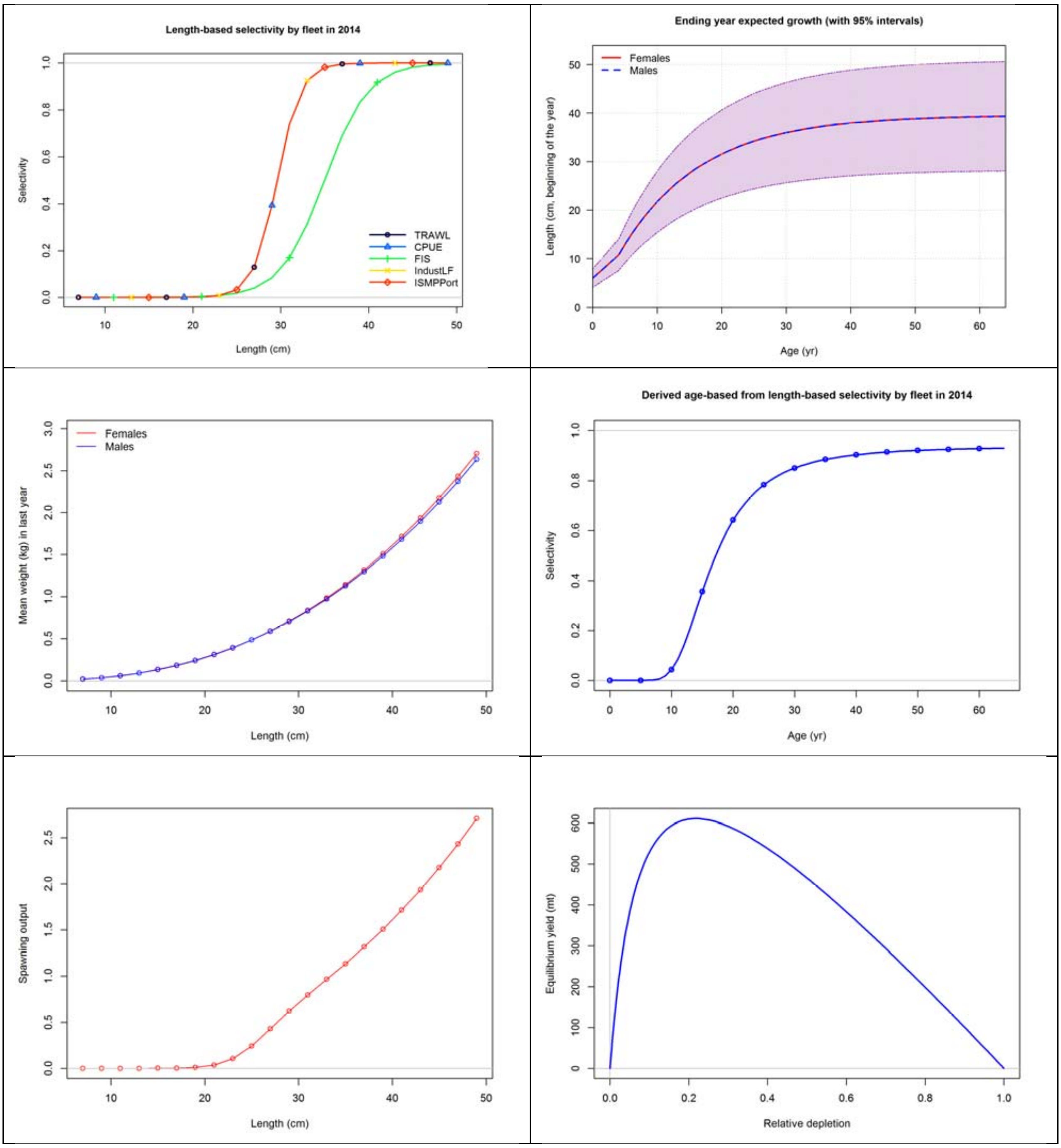

Figure 5.11. The selectivity curves for the trawl fishery and related length frequency data and of the FIS, and the predicted expected growth curves. The predicted mean weight at length, and derived age-based, length-based selectivity, the predicted depletion level of the balanced model with the 95% asymptotic confidence intervals, and the Age-0 recruit levels, again with the 95% asymptotic confidence intervals.

Table 5.11. Estimates for parameters other than recruitment deviates, with some fixed parameters for clarity. St.Dev is the approximate standard deviation for each estimate.

Parameter/Feature	Value	St.Dev.	Comment
Natural mortality *M*	0.1077	0.0023	estimated
Recruitment			
σ_R	0.335		balanced
deviates	1960 - 2005		estimated
Ln(R0)	8.5328	0.1063	estimated
First bias adjustment	1915 - 1982		estimated
Final bias adjustment	1989 - 2008		estimated
maximum bias adjustment	0.736		estimated
Growth			
CV	0.1414	0.0034	estimated
K	0.069	0.0026	estimated
L_{min}	12.4723	0.3686	estimated
L_{max}	37.939		fixed
Selectivity			
Trawl L50	29.5126	0.2146	estimated
Trawl inter-quartile	3.5381	0.2729	estimated
FIS L50	34.8884	0.6140	estimated
FIS inter-quartile	7.1225	0.4066	estimated

5.4.3 *Fits to the Data*

5.4.3.1 CPUE Data

The fits to the catch rate indices (Figure 5.12) are poor with the predicted commercial CPUE trajectory not reflecting the ups and downs of the time series from 1988/1989 – 2003/2004, and effectively taking the inverse trend to the observed CPUE trend between 2004/2005 – 2014/2015. The FIS relative abundance index follows the same trend as the commercial CPUE across their over-lapping period and the only way that the predicted FIS CPUE can fit is to expand the CV values for each data point during the re-balancing process.

The current approach used when fitting assessment models is to attempt to place emphasis on the relative index of abundance data (Francis, 2011). However, up to about 2000/2001 the degree of stock depletion was relatively minor and it was only once catches rose to about 1000 t that the depletion trajectory began to steepen (Figure 5.10). At the time of the increased catches the number of active vessels in the fishery increased from an average of about 6 (from 1989/1990 – 2001/2002) to about 9 (from 2002/2003 – 2007/2008) and then down to an average of 4 vessels to the present day (Table 5.3). A number of the vessels that left the fishery following the structural adjustment (Nov 2005 – Nov 2006) were catching significant proportions of the total Bight redfish catch (Figure 5.13). Such changes may have contributed to the failure of CPUE to reflect the predicted state of the stock. This lack of fit to the CPUE (Figure 5.12) suggests that there is some form of conflict between the CPUE data and the age and length composition data such that despite trying to push for a close fit to the relative abundance indices the model puts more emphasis on the composition data, or rather, can only fit to the age- and length-composition data. However, both the jackass morwong and silver warehou stock assessments conducted this year using the weighting procedure used here also found that the procedure failed to give the CPUE data the intended weight, instead giving the age and length data undue emphasis.

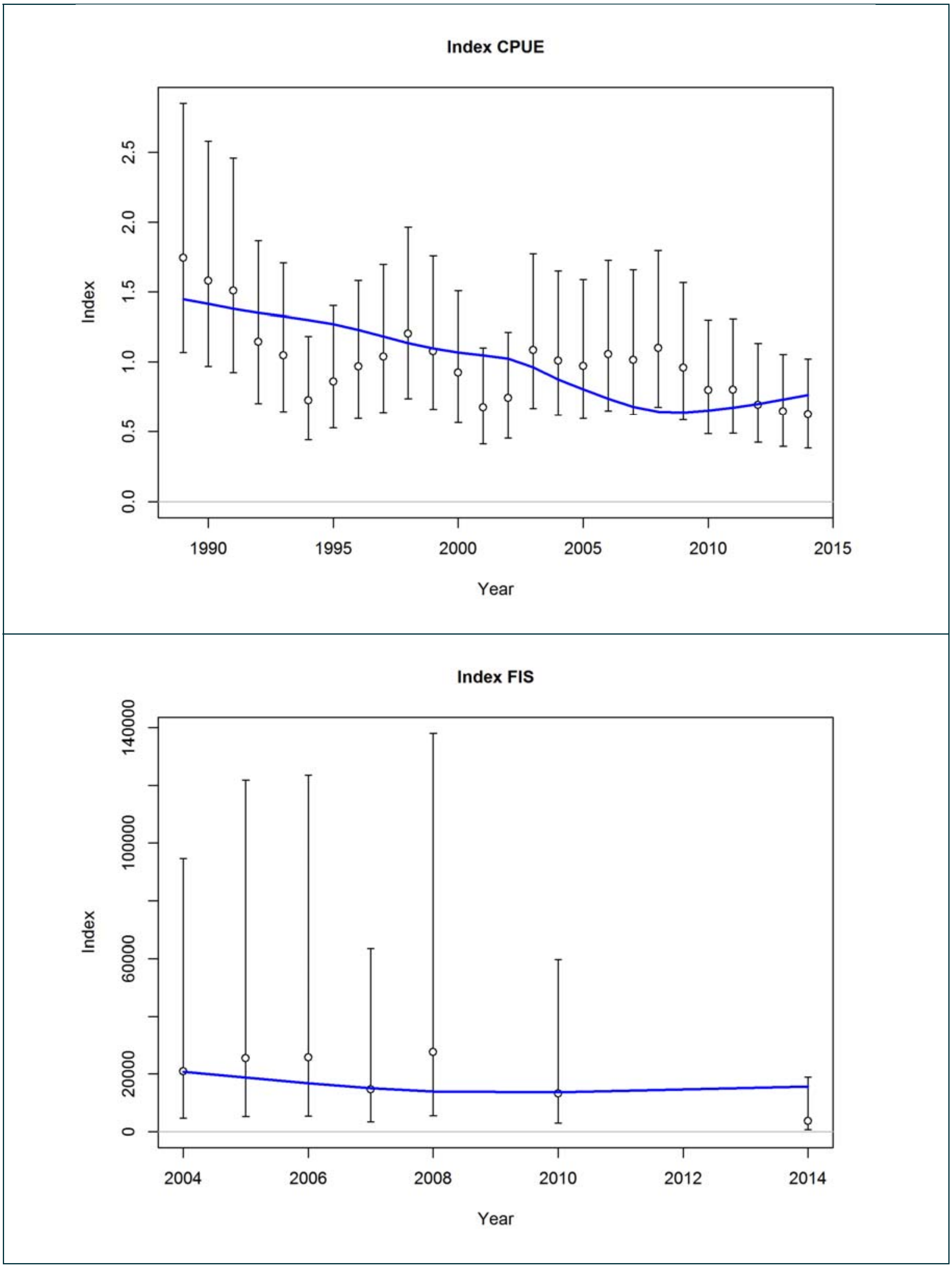

Figure 5.12. The balanced model fit to the commercial CPUE index of relative abundance and to the FIS index of relative abundance. Each year in the figures relates to the first year of each financial year combinations; e.g. 2001 = 2001/2002.

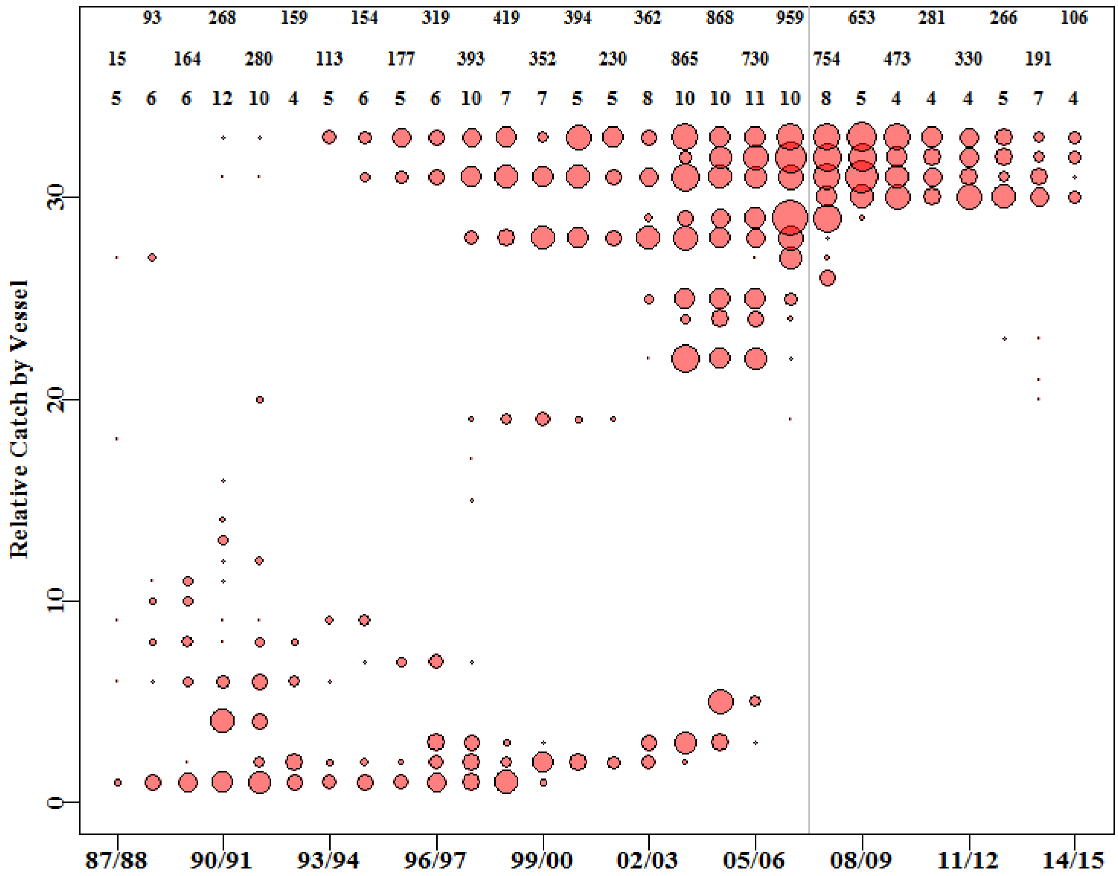

Figure 5.13. The relative catch (square root of catch) of Bight redfish per trawl vessel in the GAB fishery, with the vertical line depicting the advent of the structural adjustment. The lowest of the top three lines lists the number of vessels reporting > 1 t across all years, and the other two lines are the reported catches, staggered to improve readability.

5.4.3.2 Length Composition Data

The length composition data from the FIS shows that those fish were slightly larger on average than those from the commercial fishery (Figure 5.14) and this is reflected in their respective selectivity curves (Figure 5.11). Bight redfish tend to be selected at about 25cm and above implying that they can be 10 years or older before they are strongly selected by the fishery. This is about the same size and age at which they mature, which implies there is a proportion of the mature population not selected by the fishery and this should give the population an extra degree of resilience (Figure 5.11).

There are some years of ISMP sampling, both on-board and port samples, that appear to be inconsistent with previous and following years (on-board 2004/2005 – 2006/2007, and port 1992/1993 and 2005/2006; Figure 5.14), however the data from the FIS and the crew-member samples are more sequentially consistent, although they sometimes fail to meet the same peak levels of relative frequency. Despite these internal inconsistencies the relative fit to the length composition data, when considered across all years is close in all data streams (Figure 5.14). Further illustrations of the relative fit to the length-composition data are provided in the Appendix.

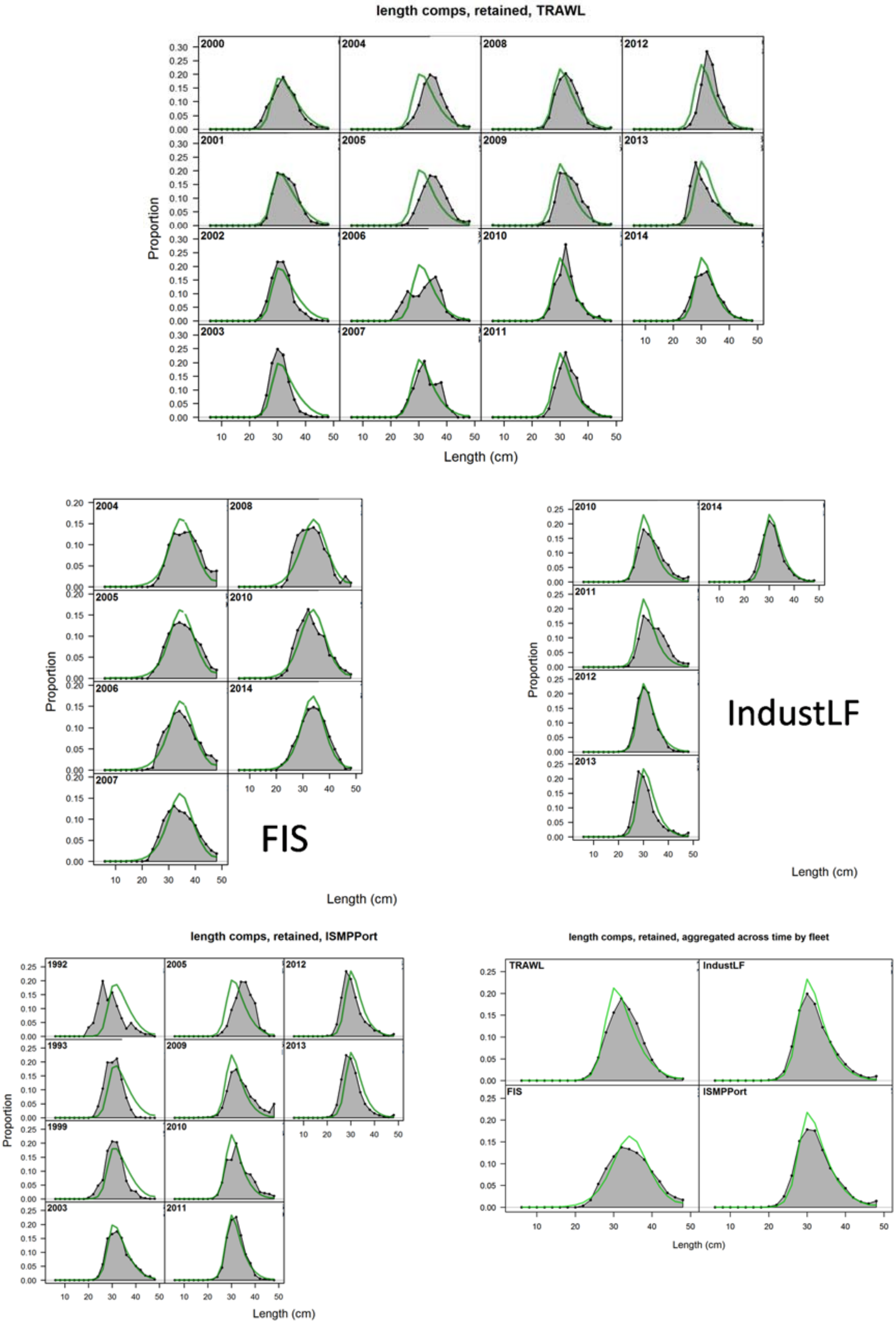

Figure 5.14. The base-case model fit to the different time-series of length-frequency composition data for the ISMP on-board data (Trawl), the FIS data, the industry on-board data (industLF), the ISMP Port data, and the summary across years for each data set. Each year in the figures relates to the first of the financial year combinations; e.g. 2001 = 2001/2002.

5.4.3.3 Age Composition Data

Age-at-Length keys are used in the model so the fits to the age-composition data are indirect. What this means is that the model can produce the implied fits to the age composition data in those years where both age- and length composition data are available (a separate age-length key should be used for each year). The model mimics the observed age data reasonably well for both the ISMP samples and the three years of the FIS (Figure 5.15).

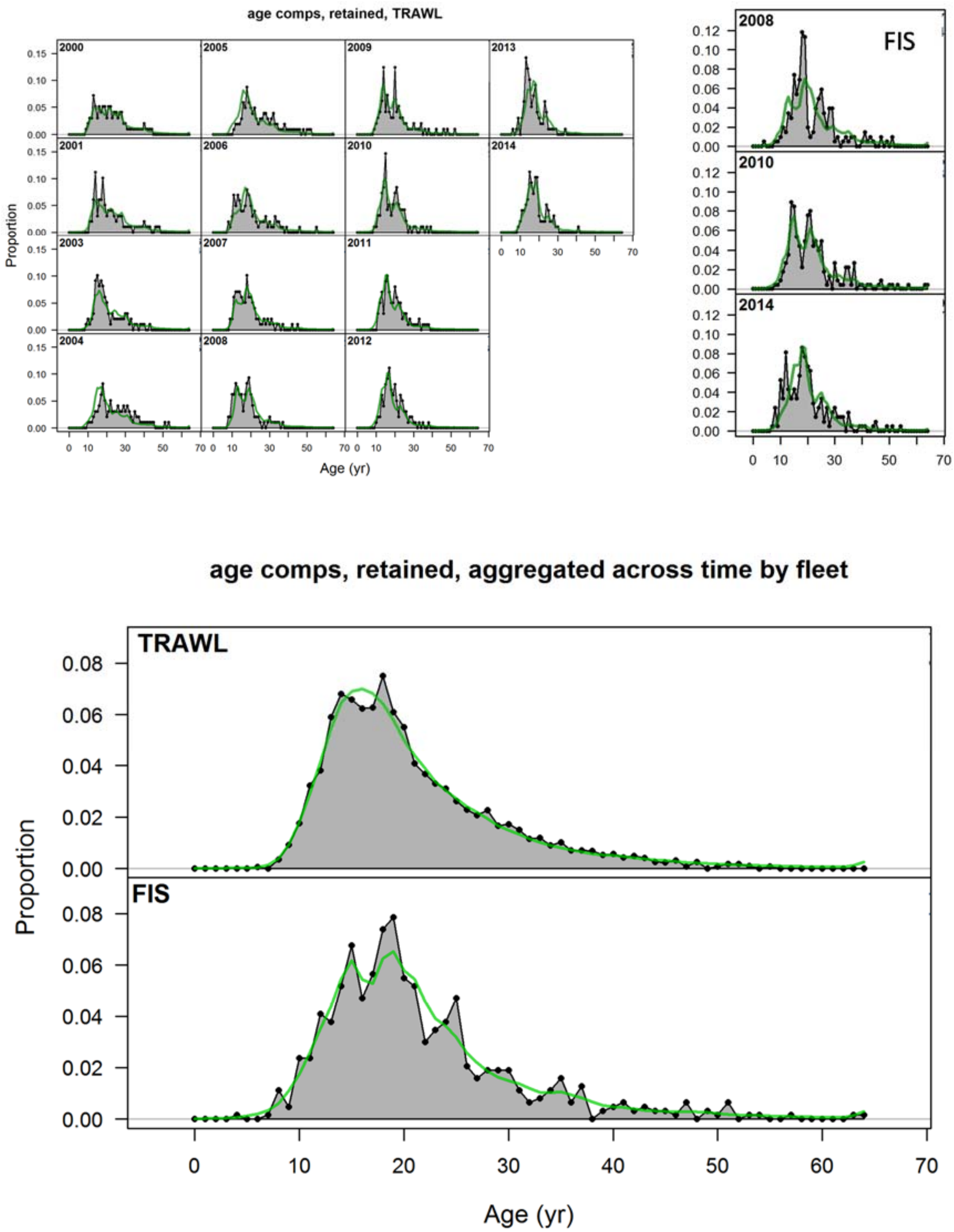

Figure 5.15. The balanced model fits to the age-composition data in each year and across all years combined. Each year in the top figure relates to the first of the financial year combinations; e.g. 2001 = 2001/2002.

The FIS data especially illustrates the progression of age classes quite well with the approximate mode of 13 – 14 year olds in 2008/2009 moving to be about 15 – 16 year olds in 2010/2011, and the approximate mode at 12 – 14 in 2010/2011 moving to be about 2013 – 2016 in 2014/2015 (Figure 5.15).

Given the far fewer number of observations from the FIS, the model still does a reasonable job of fitting to all years, as seen in the graphs of all data combined across years (Figure 5.15).

Further illustrations of the relative fit to the age-composition data are provided in the Appendix.

5.4.4 *Base-Case Assessment Outcomes*

The stock depletion level at the end of 2014/2015 is estimated to be approximately 3,437 t or 63%B_0, (Table 5.10), while the estimated, approximate MEY biomass level is 41%B_0 (Kompas *et al.*, 2011). The asymptotic confidence intervals, and the standard deviation and CVs around the biomass estimates, are likely to under-estimate the true uncertainty about the estimated biomass levels (Figure 5.16). This is why the confidence bounds are relatively tight about the median estimated spawning biomass levels. The upturn in spawning biomass following the reduction in catches from 2009/2010 is driven by reduced fishing pressure and not by greater recruitment as recruitment during this period is close to the average predicted by the stock recruitment curve in the years 2006/2007 – 2014/2015 (Figure 5.17), as fish spawning in those years would barely have entered the fishery from 2009/2010 until 2014/2015. In addition, recruitment levels are not particularly variable (Figure 5.17) and the current median stock recruitment level has barely been depressed from the maximum by the reduction of spawning biomass down to 63%B_0 (Figure 5.17).

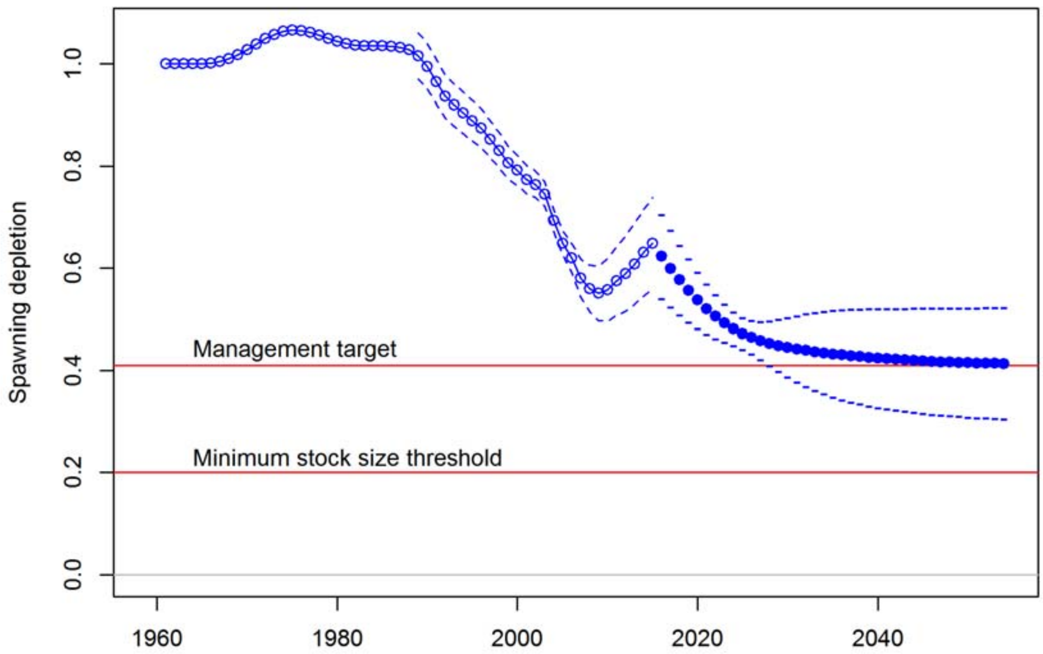

Figure 5.16 The trajectory of spawning stock depletion, including 40 years of projection used to estimate the current RBC and the long-term RBC. The stock only begins to decline slowly when fishing first begins and then accelerates downwards once catches reach about 800 – 1000t per year. With the more recent drop in catches from about 2009/2010, the stock is predicted to have increased to the present day until it ended at about 63%B_0 at the end of 2014/2015. If catches adhere to the predicted RBCs then it will take approximately 40 years for the stock to decline to the estimate MEY at 41%B_0.

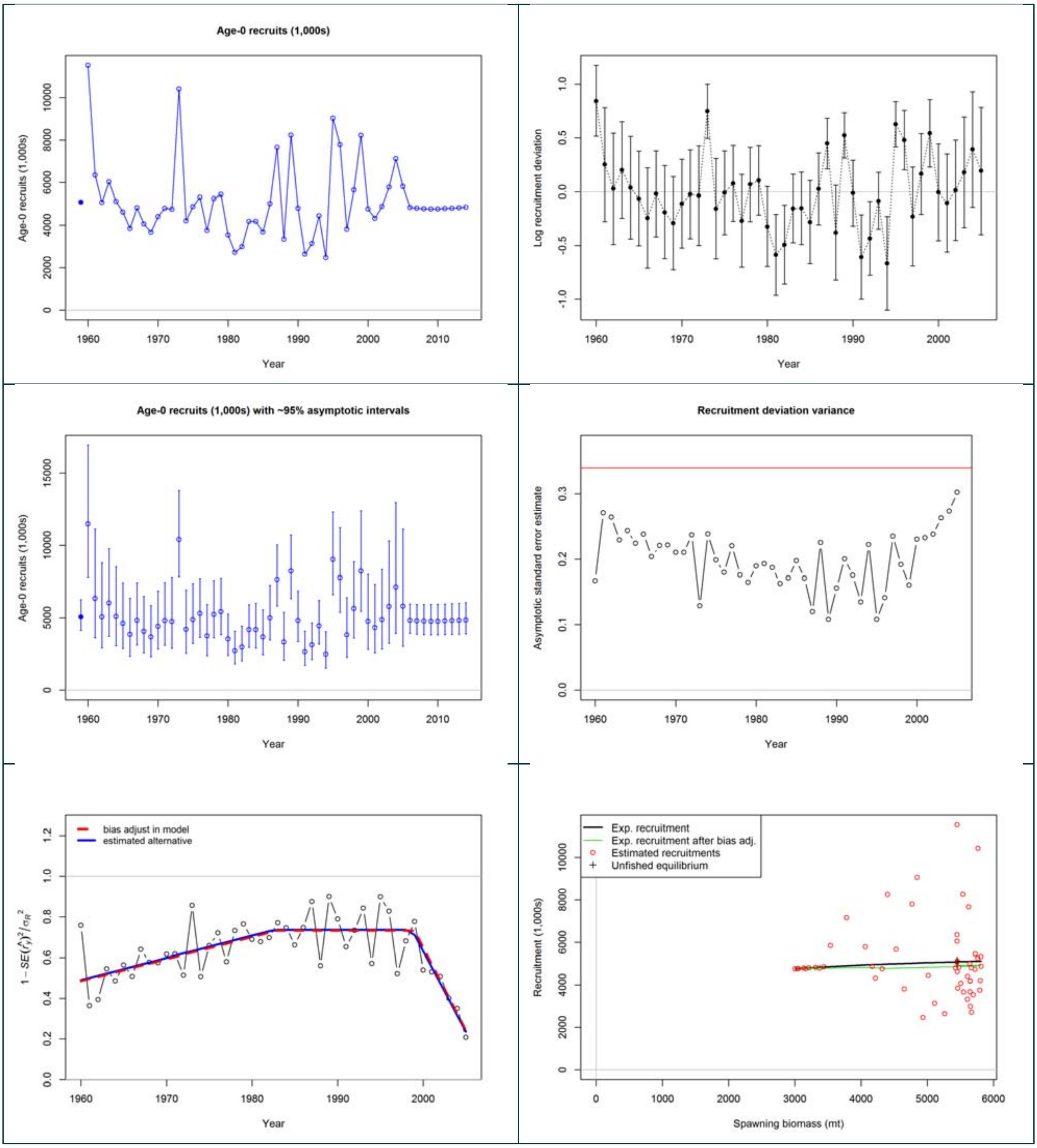

Figure 5.17. Estimation of recruitment and recruitment deviates for the base-case assessment with time trajectories given in both nominal and log-space. The final nine deviates in the middle left are not estimated but are estimated by the implied Beverton-Holt stock recruitment curve. The asymptotic standard errors of the recruitment deviates (middle right) are sufficiently low to indicate that all estimated deviates have sufficient data to allow for an adequate estimate. The bias-adjustment graph illustrates the degree to which the estimates of recruitment deviates require correction for their level of variation (Methot and Taylor, 2011). The implied stock recruitment curve (bottom right) illustrates that the stock depletion level has not been sufficient to alter the average recruitment levels significantly.

The predicted recruitment dynamics differ from those previously estimated, which may be related to the advent of more ageing data from the FIS and additional length-composition data streams. The increases in the suggested level of SigmaR means that the recruitment deviates are more free to vary. In the period between 1960 and 1970 there are now predicted to be some minor jumps in recruitment and these appear to be a direct result of the inclusion of the ageing data from the FIS (the yellow line in Figure 5.18). In addition this has split the major mode of recruitment in about 1988 into two spikes with a low in between.

The inclusion of recruitment estimates for more recent years also, not surprisingly, indicates some relatively low and some relatively high values. There are no prolonged periods of high or low recruitment apparent in the time series (Figure 5.18).

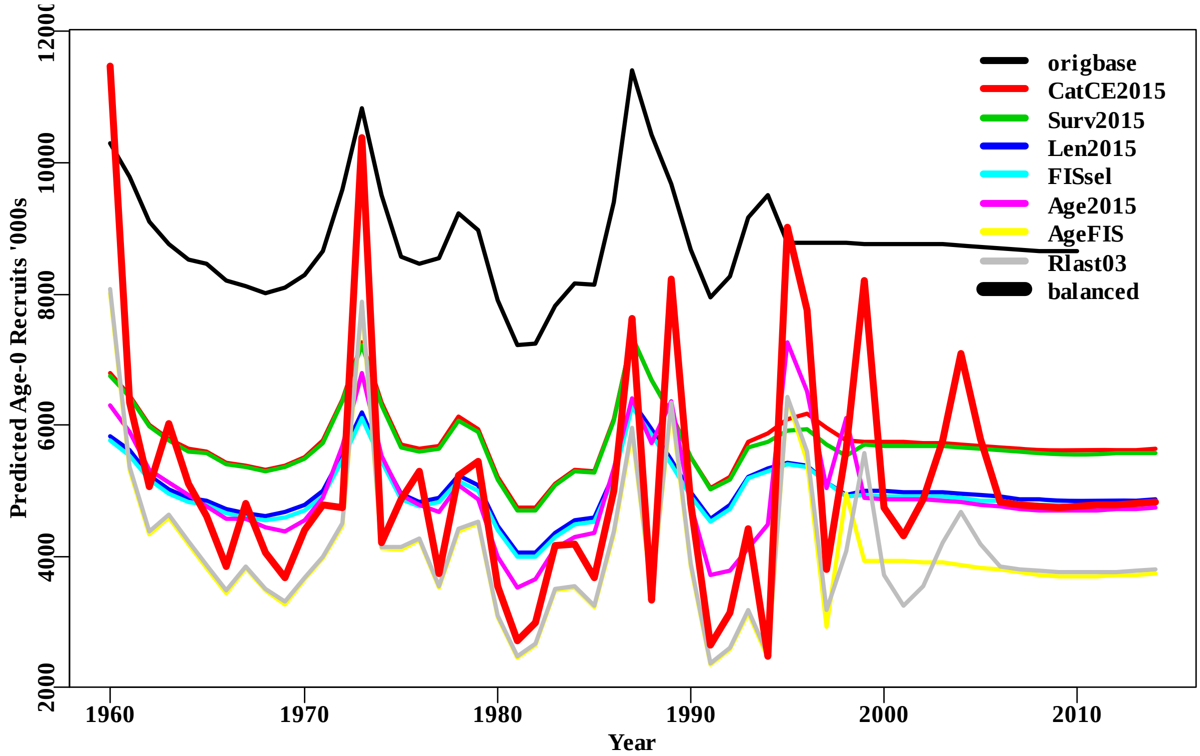

Figure 5.18. The sequence of expected recruitment levels through time in the different scenarios.

This upswing in spawning biomass when catches declined should be informative about the relative productivity of the stock and how it responds to changes in fishing mortality. Across the period of the forty year projection the predicted decline in projected spawning biomass is initially relatively rapid (although taking ten years to drop into the low 40% levels) and then tailing off as the median levels approach the target biomass depletion level. This predicted trajectory, however, depends upon the estimated RBC being caught each year, which, given recent catches and reports of difficulty in catching the fish, seems unlikely.

The recruitment levels and recruitment deviates through the period of the fishery have not varied to any extreme extent (Figure 5.17). There have been no extensive periods of below or above average recruitment levels predicted throughout the fishery. In fact, the variability in the recruitment (σ_R = 0.335) considered optimal in the model fitting and balancing process is low in absolute terms relative to many other species assessed within the SESSF. The effect of increasing and decreasing this variation is examined in the sensitivities (Table 5.14).

The 2016/2017 recommended biological catch (RBC) under the 20:35:41 harvest control rule is 862 t and the long term yield (assuming average recruitment in the future) is 537 t (Table 5.12; Table 5.14).

Averaging the RBC over the three year period 2016-2018, the average RBC is 828 t and over the five year period 2016-2020, the average RBC is 797 t (Table 5.12; Table 5.14).

Even though the precision of this assessment is much improved over earlier assessments (Table 5.10), given that the data has only now become informative about the stock depletion levels and the impact of the fishing catch history on the stock, the estimates of stock biomass and current depletion level must still be treated as approximate until further data collections confirm the revisions in the model outputs.

Table 5.12. The predicted total exploitable biomass, the Female Spawning Biomass, and the observed and predicted catches from the forecast projections. The bolded rows represent the predicted RBCs for the 2016/2017 fishing year and the long-term RBC that should maintain the stock at the target of 41%B_0. See Table 5.17 for the projection outcomes for all years.

Year	Total Exploitable Biomass	Spawning Biomass	Catch	Depletion
Unfished	16041.700	5451.190	0	1
1988	15730.500	5604.690	85.651	1.028
1989	15509.600	5537.390	170.833	1.016
1990	15336.600	5426.020	281.808	0.995
1991	15048.300	5264.040	265.612	0.966
1992	14769.100	5108.240	120.698	0.937
2014	12047.600	3436.760	238.327	0.630
2015	12186.500	3537.980	238.327	0.649
2016	**11782.800**	**3396.370**	**862.091**	**0.623**
2017	11421.300	3265.200	827.194	0.599
2018	11099.200	3143.400	795.039	0.577
2019	10813.900	3030.83	765.023	0.556
2020	10563.100	2927.96	736.909	0.537
2052	8873.250	2258.830	538.026	0.414
2053	8867.130	2256.700	537.437	0.414
2054	**8861.560**	**2254.770**	**536.903**	**0.414**

5.4.5 *Sensitivity Tests*

The sensitivity tests demonstrate that the assessment outcomes are very sensitive to the assumed value for M, the natural mortality (Figure 5.19; Table 5.14). In addition, although not as extreme as the effects of the natural mortality altering the size at median maturity and doubling the weight on CPUE were also influential on the absolute estimates of B_0 and hence of the final depletion.

The other sensitivities considered remained grouped relatively closely around the balanced base-case outcomes (Figure 5.19; Table 5.14 - Table 5.16).

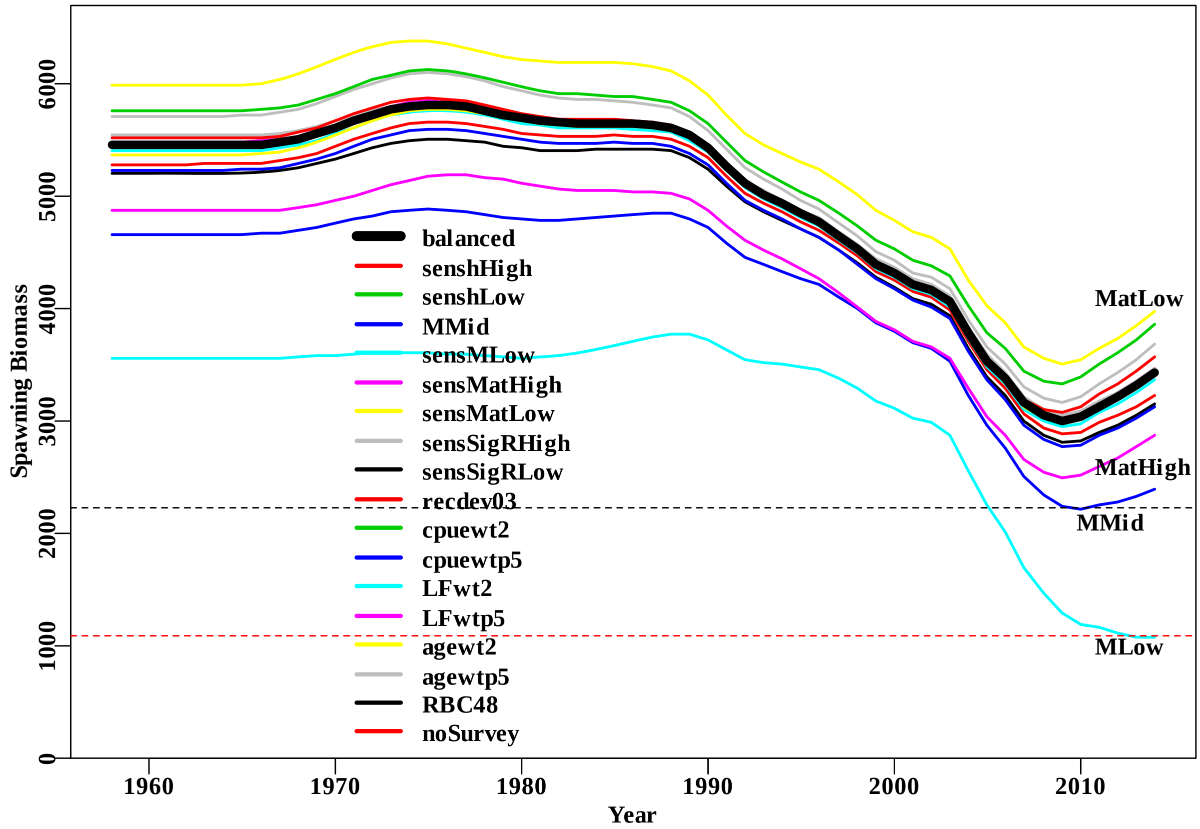

Figure 5.19. The effect on the predicted spawning biomass trajectory of the sensitivity tests on different assumptions and data weightings. The sensitivity that tested a relatively high natural mortality was omitted as its low point in about 2008 was almost at the high point of the next highest.

Altering the weights on the different data streams had some effects on the model outcomes especially the halving and doubling the weights on the length composition data, which increased and decreased the depletion levels rather more than other treatments (Table 5.14). However, it is not valid to compare the likelihoods from such sensitivity tests although the unweighted likelihoods can still sometimes be illuminating, and a consideration of their effects on the model's implications for the stock status remains useful. The overall fit of the model improved with greater weight on the length composition data and declined with a lower weight.

With the different weights on the CPUE indices (log-books and FIS) the reverse was true in that the model fit improved when less weight was placed on the CPUE. Care is needed with such statements however. A consideration of the different weights applied to the age-composition data illustrate the reasons why total likelihood comparisons can be misleading (and are invalid). Because the age-related likelihoods are large to start with including a multiplier alters their values enormously (Table 5.15) even though they have only a small effect on the biomass related model outcomes (Table 5.14).

The sensitivity tests on the particular parameters in the model (steepness, natural mortality, size at 50% maturity, and the permissible variation of the recruitment deviates (SigmaR) are directly comparable, although it needs to be remembered that the sensitivities are not rebalanced and so the comparisons remain only approximate.

The effect of varying steepness was relatively minor on both the likelihoods and the stock status, while the effect of varying the size at 50% maturity was also very minor on the likelihood of the model fit but was more influence on the stock status with the base-case depletion being 63% in 2014/2015 which dropped to 59% with a smaller size-at-maturity and rose to 66.4% with a higher size-at-maturity.

The effect of changing the SigmaR value alters how variable the recruitment deviates can be from year to year. Not surprisingly therefore, when SigmaR is increased the age-component likelihood improves and when it is decreased that likelihood increases in size (smaller is better). However, once again the effect on the stock depletion status is minor varying the estimate from 60% – 64%.

Far more influential is the effect of varying the natural mortality. As one of the major factors affecting productivity this influenced the likelihoods for all data streams although it did so in different directions. A higher *M* value improved the fit to the two CPUE series and to the age-composition data but decreased the quality of fit to the length-composition data, and visa-versa when *M* was reduced.

Because the sensitivity tests demonstrated that the assessment model is relatively sensitive to the value of natural mortality this was examined more closely by estimating a likelihood profile for natural mortality (Figure 5.20; Table 5.13). Approximate 95% confidence intervals can be obtained and these suggest that, in terms of the uncertainty related to natural mortality, with the best estimate of the mean current depletion of 63% at the end of 2014/2015, the 95% confidence interval bounds would be between 57% and 69%.

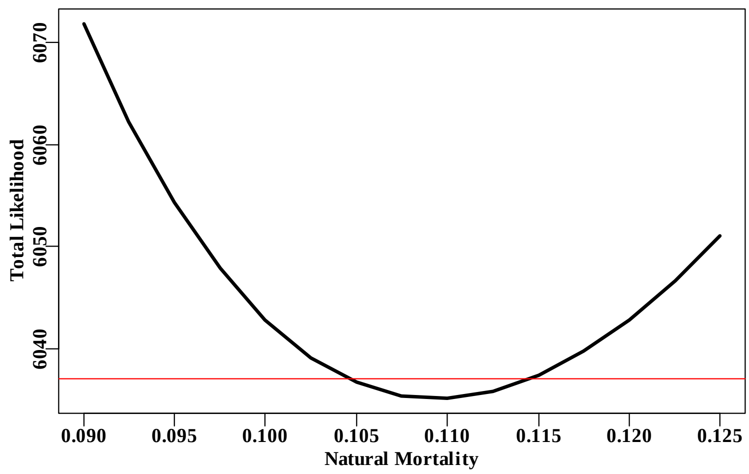

Figure 5.20. A likelihood profile for natural mortality. The values for natural mortality are fixed in the model instead of being estimated and all other parameters estimated as usual. The red line denotes the approximate 95% confidence bounds (Venzon and Moolgavkar, 1988).

Table 5.13. The outcomes for a likelihood profile on natural mortality. The approximate likelihood profile confidence intervals are bounded where the total likelihood is 6037.0 (6035.08 + 1.92).

M	TotalLike	TotalCE	TotalLF	TotalAge	B0	Bcurr	Depletion
0.09	6071.84	-10.00	47.56	6034.28	4210.790	1830.260	0.435
0.0925	6062.23	-11.89	47.93	6026.20	4344.780	1997.800	0.460
0.095	6054.26	-13.61	48.29	6019.58	4489.370	2181.050	0.486
0.0975	6047.83	-15.15	48.64	6014.34	4646.040	2381.830	0.513
0.1	6042.81	-16.52	48.98	6010.36	4816.430	2602.320	0.540
0.1025	6039.13	-17.74	49.30	6007.56	5002.460	2845.080	0.569
0.105	6036.68	-18.79	49.62	6005.85	5206.350	3113.160	0.598
0.1075	6035.36	-19.70	49.92	6005.14	5430.710	3410.240	0.628
0.11	6035.08	-20.46	50.20	6005.34	5678.680	3740.700	0.659
0.1125	6035.76	-21.09	50.47	6006.38	5954.010	4109.900	0.690
0.115	6037.34	-21.58	50.72	6008.19	6261.300	4524.370	0.723
0.1175	6039.72	-21.94	50.96	6010.69	6606.160	4992.150	0.756
0.12	6042.83	-22.17	51.18	6013.81	6995.600	5523.290	0.790
0.1225	6046.62	-22.27	51.39	6017.50	7438.400	6130.390	0.824
0.125	6051.01	-22.26	51.58	6021.69	7945.740	6829.540	0.860

5.4.5.1 The Alternative Harvest Strategy 20:35:48

The inclusion of the projection with a 20:35:48 Harvest Control Rule is not strictly a sensitivity on the model fit as it has no effect on the fit (Table 5.15 and Table 5.16) as it only influences dynamic events during the projection period.

Table 5.14. Summary of the outcomes for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for tuned models (base-case and RBC48). The likelihoods in the italicized cases should not be compared with the other sensitivities.

	Case	SSB_0	SSB_{2014}	SSB_{2014}/SSB_0	M	RBC_{2016}	$RBC_{2016\text{-}8}$	$RBC_{2016\text{-}20}$	$RBC_{longterm}$
Base-Case	**base case 20:35:41**	**5451**	**3437**	**0.6305**	**0.10772**	**862**	**828**	**797**	**537**
hHigh	Fix steepness $h = 0.85$	5454	3460	0.6345	0.10773				
hLow	Fix steepness $h = 0.65$	5449	3409	0.6257	0.10771				
MHigh	$M = 0.125$	7946	6830	0.8595	0.12500				
Mmid	$M = 0.0977$	4659	2399	0.5148	0.09770				
MLow	$M = 0.075$	3558	1082	0.3041	0.07500				
MatHigh	50% maturity at 23cm	4868	2880	0.5917	0.10771				
MatLow	50% maturity at 27cm	5980	3970	0.6639	0.10773				
SigRHigh	$\sigma_R = 0.235$	5713	3689	0.6457	0.10919				
SigRLow	$\sigma_R = 0.435$	5205	3148	0.6047	0.10600				
recdev03	rec deviates only to 2003	5284	3228	0.6109	0.10694				
LFwtx2	wt x 2 length comp	5758	3865	0.6712	0.10898				
LFwtx0.5	wt x 0.5 length comp	5232	3129	0.5981	0.10672				
cpuewtx2	wt x 2 CPUE	5402	3372	0.6243	0.10719				
cpuewtx0.5	wt x 0.5 CPUE	5480	3476	0.6343	0.10805				
agewtx2	wt x 2 age comp	5368	3432	0.6393	0.10782				
agewtx0.5	wt x 0.5 age comp	5542	3470	0.6262	0.10732				
RBC48	20:35:48 HCR	5451	3437	0.6305	0.10772	659	648	637	485
noSurvey	No Survey data (CE, LF, age)	5514	3567	0.6469	0.10779				

Table 5.15. Summary of likelihood components for the base-case and sensitivity tests. Except for the four columns of Totals, Likelihood components are unweighted. See Table 5.16 to see how the likelihoods deviate from the base-case. The likelihoods in the italicized cases should not be compared with the other sensitivities.

Sensitivity	TotalLike	TotalCE	TotalLF	TotalAge	CPUE	FISCE	TrawlLF	FISLF	IndustLF	PortLF	TrawlAge	FISAge
Base-Case	6035.31	-19.77	49.94	6005.14	-20.23	0.46	16.17	23.61	3.20	6.96	5235.24	769.90
hHigh	6035.17	-19.83	49.94	6005.05	-20.29	0.46	16.17	23.62	3.20	6.95	5235.20	769.85
hLow	6035.45	-19.70	49.94	6005.21	-20.15	0.45	16.17	23.61	3.20	6.96	5235.28	769.93
MHigh	6051.01	-22.26	51.58	6021.69	-23.13	0.87	16.65	24.53	3.31	7.09	5252.10	769.59
Mmid	6047.37	-15.27	48.66	6013.97	-15.47	0.20	15.74	22.98	3.11	6.83	5243.28	770.70
MLow	6169.37	5.38	45.36	6118.63	5.74	-0.36	14.43	21.51	2.89	6.52	5343.15	775.48
MatHigh	6035.32	-19.76	49.94	6005.14	-20.21	0.46	16.17	23.61	3.20	6.96	5235.25	769.89
MatLow	6035.26	-19.79	49.94	6005.10	-20.25	0.46	16.17	23.62	3.20	6.96	5235.22	769.88
SigRHigh	6030.01	-20.24	49.92	6000.33	-20.75	0.51	16.18	23.60	3.19	6.96	5230.95	769.38
SigRLow	6045.12	-19.07	49.98	6014.21	-19.46	0.39	16.19	23.64	3.21	6.94	5243.57	770.63
recdev03	6037.55	-19.26	49.99	6006.82	-19.67	0.41	16.17	23.62	3.24	6.96	5236.39	770.43
LFwtx2	6013.90	-42.13	50.15	6005.88	-21.61	0.54	16.26	23.73	3.20	6.96	5236.46	769.42
LFwtx0.5	6045.45	-9.24	49.79	6004.90	-18.86	0.38	16.11	23.55	3.19	6.94	5234.76	770.14
cpuewtx2	6084.28	-19.53	96.58	6007.23	-19.98	0.45	15.60	23.07	2.97	6.65	5236.91	770.32
cpuewtx0.5	6009.97	-19.92	25.81	6004.07	-20.38	0.46	16.87	24.03	3.45	7.29	5234.67	769.40
agewtx2	12029.75	-19.48	51.44	11997.80	-19.95	0.46	16.79	23.93	3.43	7.28	5229.85	769.05
agewtx0.5	3036.38	-20.32	48.52	3008.18	-20.78	0.46	15.68	23.22	2.98	6.64	5245.78	770.58
RBC48	6035.31	-19.77	49.94	6005.14	-20.23	0.46	16.17	23.61	3.20	6.96	5235.24	769.90
noSurvey	5235.37	-19.88	25.54	5229.71	-19.88	0.00	15.02	0.00	3.39	7.13	5229.71	0.00

Table 5.16. Summary of likelihood components for the base-case and sensitivity tests with the values from the sensitivity tests subtracted from the base-case values. Negative values denote improved model fits, positive values reduced model fits. Except for the four columns of Totals, Likelihood components are unweighted. The likelihoods in the italicized cases should not be compared with the other sensitivities.

Sensitivity	TotalLike	TotalCE	TotalLF	TotalAge	CPUE	FISCE	TrawlLF	FISLF	IndustLF	PortLF	TrawlAge	FISAge
Base-Case	6035.31	-19.77	49.94	6005.14	-20.23	0.46	16.17	23.61	3.20	6.96	5235.24	769.90
hHigh	-0.14	-0.06	0.00	-0.09	-0.06	0.01	0.00	0.01	0.00	0.00	-0.04	-0.05
hLow	0.14	0.07	0.00	0.07	0.08	-0.01	0.00	-0.01	0.00	0.00	0.04	0.03
MHigh	15.70	-2.49	1.64	16.55	-2.90	0.41	0.48	0.92	0.11	0.14	16.86	-0.30
Mmid	12.06	4.51	-1.28	8.83	4.76	-0.25	-0.44	-0.63	-0.09	-0.12	8.04	0.80
MLow	134.06	25.15	-4.59	113.49	25.97	-0.82	-1.74	-2.10	-0.31	-0.44	107.91	5.58
MatHigh	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
MatLow	-0.05	-0.02	0.00	-0.04	-0.02	0.00	0.00	0.00	0.00	0.00	-0.02	-0.02
SigRHigh	-5.30	-0.47	-0.02	-4.81	-0.52	0.05	0.00	-0.02	-0.01	0.01	-4.29	-0.52
SigRLow	9.81	0.70	0.04	9.07	0.77	-0.07	0.01	0.03	0.01	-0.01	8.33	0.74
recdev03	2.24	0.51	0.05	1.68	0.56	-0.05	0.00	0.01	0.04	0.01	1.15	0.53
LFwtx2	-21.41	-22.36	0.21	0.74	-1.38	0.09	0.09	0.11	0.00	0.01	1.22	-0.48
LFwtx0.5	10.14	10.53	-0.15	-0.24	1.37	-0.07	-0.07	-0.07	-0.01	-0.01	-0.48	0.25
cpuewtx2	48.97	0.24	46.64	2.09	0.25	-0.01	-0.57	-0.54	-0.23	-0.31	1.67	0.43
cpuewtx0.5	-25.34	-0.15	-24.13	-1.07	-0.15	0.01	0.69	0.41	0.25	0.33	-0.57	-0.50
agewtx2	5994.44	0.29	1.49	5992.66	0.28	0.00	0.62	0.32	0.23	0.32	-5.39	-0.85
agewtx0.5	-2998.93	-0.55	-1.42	-2996.96	-0.55	0.01	-0.49	-0.39	-0.22	-0.32	10.54	0.68
RBC48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
noSurvey	-799.94	-0.11	-24.40	-775.43	0.35	-0.46	-1.16	-23.61	0.19	0.18	-5.53	-769.90

Table 5.17. Tabulated deterministic output from the projections. The filled dots in Figure 5.16 are the year and Depletion column values (as proportions not percentages).

Year	Spawning Biomass	RBC 20:35:41	Total Biomass	Exploitable Biomass	Harvest Rate (%)	Depletion (%)
2015	3538.0	900.6	12280.7	12186.5	7.39	64.90
2016	3396.4	862.1	11876.5	11782.8	7.32	62.31
2017	3265.2	827.2	11514.6	11421.3	7.24	59.90
2018	3143.4	795.0	11192.0	11099.2	7.16	57.66
2019	3030.8	765.0	10906.2	10813.9	7.07	55.60
2020	2928.0	736.9	10655.0	10563.1	6.98	53.71
2021	2835.5	710.8	10435.9	10344.5	6.87	52.02
2022	2753.9	686.9	10246.5	10155.4	6.76	50.52
2023	2683.3	665.5	10084.0	9993.4	6.66	49.22
2024	2623.4	646.8	9945.6	9855.2	6.56	48.12
2025	2573.3	630.8	9828.0	9737.9	6.48	47.21
2026	2531.9	617.5	9728.1	9638.2	6.41	46.45
2027	2497.9	606.5	9642.8	9553.2	6.35	45.82
2028	2469.8	597.5	9569.6	9480.1	6.30	45.31
2029	2446.5	590.2	9505.9	9416.6	6.27	44.88
2030	2426.7	584.2	9449.9	9360.7	6.24	44.52
2031	2409.7	579.2	9399.9	9310.9	6.22	44.20
2032	2394.6	575.0	9354.9	9266.0	6.21	43.93
2033	2381.1	571.3	9314.0	9225.1	6.19	43.68
2034	2368.8	568.0	9276.6	9187.8	6.18	43.45
2035	2357.3	565.0	9242.3	9153.5	6.17	43.24
2036	2346.7	562.2	9210.8	9122.1	6.16	43.05
2037	2336.8	559.5	9181.8	9093.2	6.15	42.87
2038	2327.7	557.1	9155.3	9066.7	6.14	42.70
2039	2319.2	554.8	9131.0	9042.5	6.14	42.54
2040	2311.3	552.7	9108.9	9020.5	6.13	42.40
2041	2304.2	550.7	9088.8	9000.4	6.12	42.27
2042	2297.6	548.9	9070.6	8982.3	6.11	42.15
2043	2291.7	547.3	9054.1	8965.8	6.10	42.04
2044	2286.4	545.8	9039.2	8951.0	6.10	41.94
2045	2281.5	544.4	9025.8	8937.5	6.09	41.85
2046	2277.2	543.2	9013.6	8925.4	6.09	41.77
2047	2273.3	542.1	9002.6	8914.4	6.08	41.70
2048	2269.8	541.1	8992.7	8904.5	6.08	41.64
2049	2266.6	540.2	8983.7	8895.5	6.07	41.58
2050	2263.8	539.4	8975.5	8887.4	6.07	41.53
2051	2261.2	538.7	8968.1	8880.0	6.07	41.48
2052	2258.8	538.0	8961.3	8873.2	6.06	41.44
2053	2256.7	537.4	8955.2	8867.1	6.06	41.40
2054	2254.8	536.9	8949.6	8861.6	6.06	41.36

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5.6 Appendix A

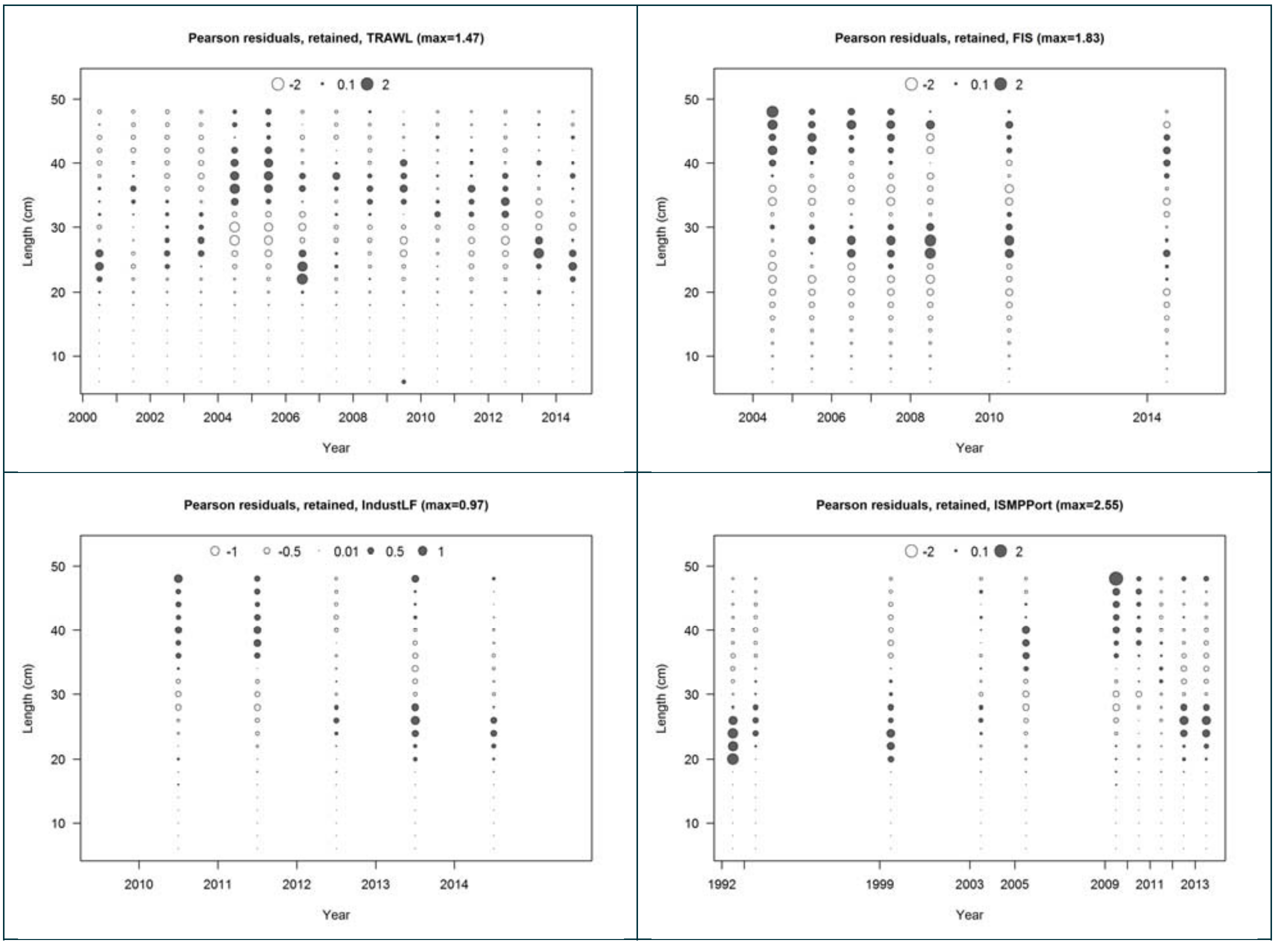

Figure 5.21. Residuals from the annual length composition data (retained) for Bight redfish displayed by year and fleet (TRAWL – ISMP_onboard).

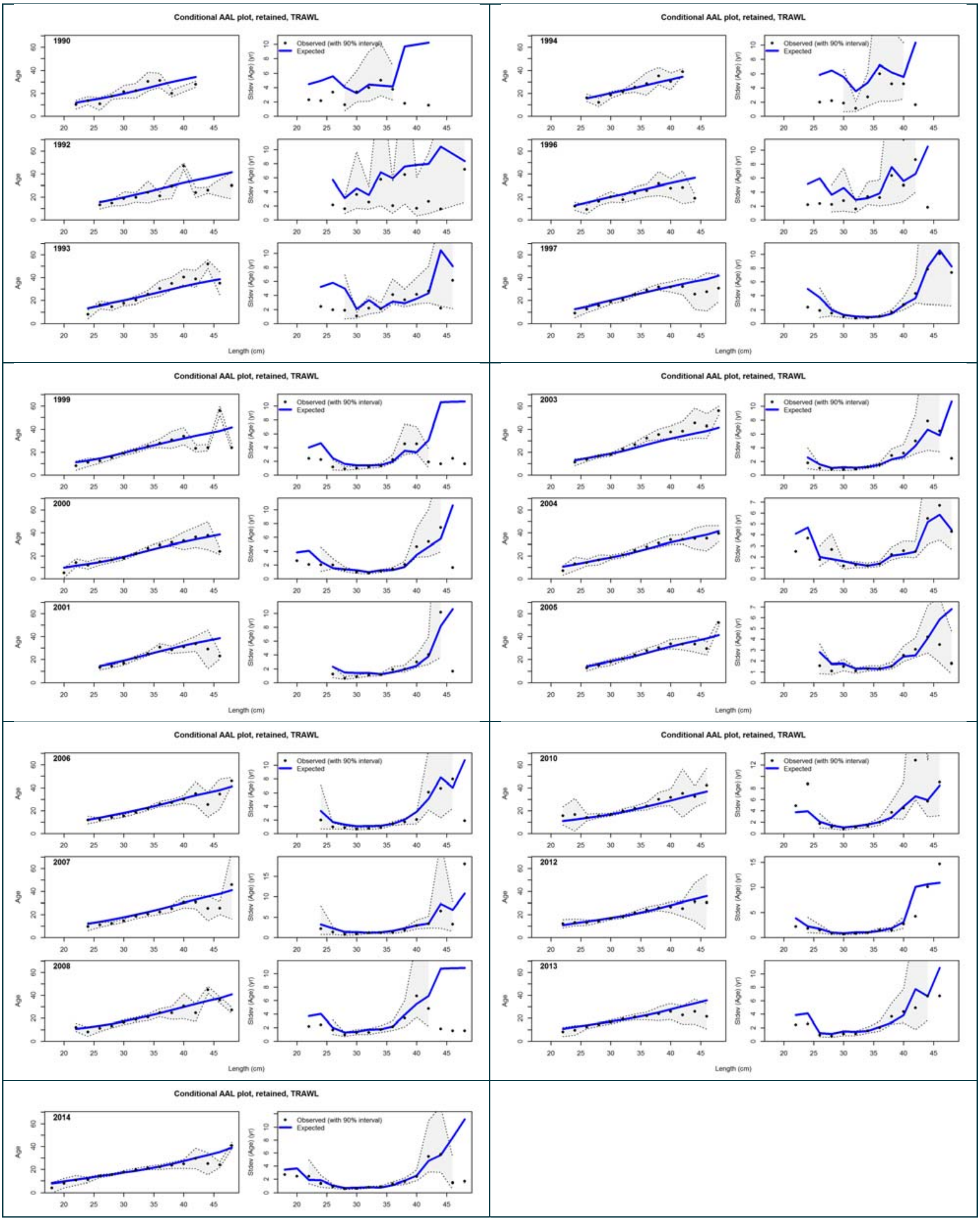

Figure 5.22. Conditional age-at-length plots illustrating the ages expected each year from the sampled length composition data and the age-length key for the year.