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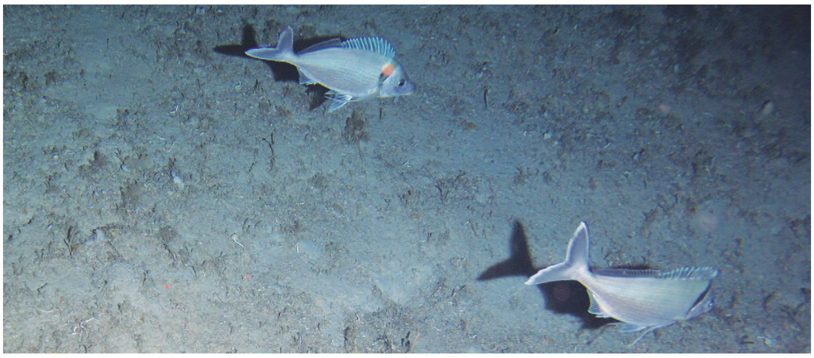
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2016 and 2017



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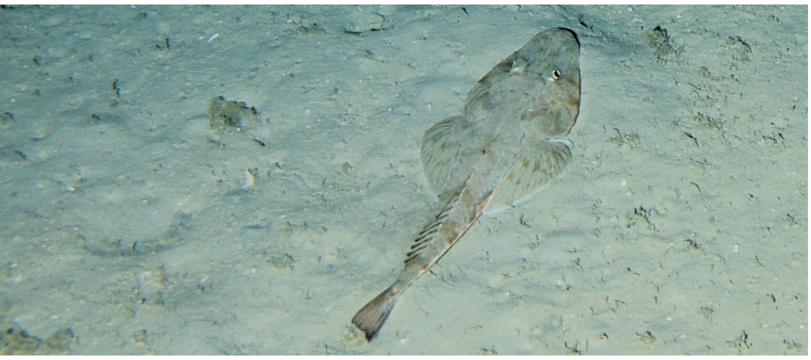

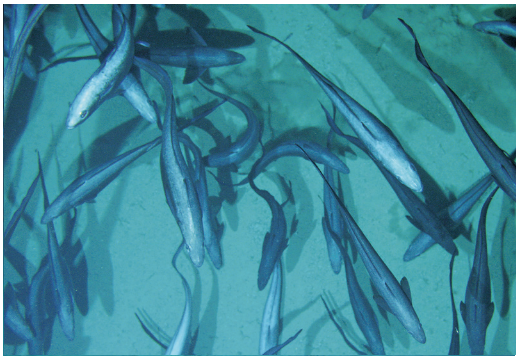

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Cover photographs

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

Report structure

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

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

Part 1: 2016

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Australian Fisheries Management Authority

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

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16. Deepwater Flathead (*Neoplatycephalus conatus*) stock assessment using data to 2015/2016

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16.1 Summary

This document updates the 2013 assessment of Deepwater Flathead (*Platycephalus conatus*) by including new data from 2012/2013 – 2014/2015) to provide estimates of stock status in the Great Australian Bight at the start of 2016/17 (end of 2015/2016). This assessment was performed using the stock assessment package Stock Synthesis (v3.24z) and included data from AFMA log-books, the ISMP sampling program, the ageing facility, and from Industry sampling programs and the GAB Fishery Independent Trawl Survey. For the first time the ISMP data was divided into the on-board and Port based samples, the length and age composition data from the FIS was used for the first time, and the Industry collected length composition data was also used for the first time.

The base-case assessment estimates that the female spawning stock biomass at the start of 2016/2017 was 45.0% of unexploited female spawning stock biomass (SSB_0). The 2017/2018 recommended biological catch (RBC) under the agreed 20:35:43 harvest control rule is 1155 t and the long-term yield (assuming average recruitment in the future) is 1093 t. Averaging the RBC over the three year period 2017/2018 – 2019/2020, generates a three year RBC of 1128 t and over the five year period 2016/2017 – 2020/2021, the average RBC would be 1115 t. The reduction reflects the gradually declining RBC predicted when projecting the assessment model forward to a depletion level of 43%B_0. As expected lower RBCs are generated using a 20:35:48 harvest control rule.

The unexploited female spawning biomass in 2016/2017 was estimated as 11,046 t. While this is an increase of 1719 t over the estimate made in 2012 there has been little change in the stock status with the stock still estimated to be at 45% unfished biomass (2% above the estimate MEY value).

The Forecast RBCs for Deepwater Flathead based on the 20:35:43 Harvest Control Rule	
Forecast	20:43
2017/2018 RBC	1155
17/18 – 19/20 RBC	1128
17/18 – 19/20 RBC	1115
Long Term Yield	1093

16.2 Introduction

16.2.1 *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. Deepwater Flathead are endemic to Australia and inhabit waters from NW Tasmania, west to north of Geraldton in WA in depths from 70m to more than 510m (Kailola *et al*., 1993; Gomon *et al*., 2008; www.fishbase.org). Bight Redfish are also endemic to southern Australia, occurring from off Lancelin in WA to Bass Strait in depths from 10m to 500m. The two species are often caught in the same trawl tows although Bight Redfish is most commonly taken in the east of the GAB. This document focusses on the stock assessment for Deepwater Flathead.

16.2.2 *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 relatively informal method were 32,000t and 12,000t respectively (Tilzey and Wise 1999). Error bounds on these estimates could not be calculated.

Wise and Tilzey (2000) summarised the data for the GABTF focusing on Deepwater Flathead and Bight Redfish, the two principle commercial species in shelf waters. They produced the first attempt to assess the status of these Deepwater Flathead and Bight Redfish populations using age- and sex-structured stock assessment models. The virgin total biomass estimates for the Deepwater Flathead base case model were 53,760t (95% confidence interval is 2,488-105,032t). In 2002 an updated assessment was carried out including data up to 2001. The unexploited biomass estimates for the Deepwater Flathead base case model was then 12,876t (95%CI=11,928-13,824).

GABTF assessments in 2005 (Wise and Klaer, 2006; Klaer, 2007) 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 levels estimated for the base case models from the assessment models were 20,418t and 13,932t for Deepwater Flathead and Bight Redfish, respectively. The absolute biomass estimate from the survey at that time was consistent with other fishery data for deepwater flathead, but was much greater than the biomass modelled without the survey for Bight redfish. Survey estimates are now treated as indices of relative abundance separate from that obtained from the standardized Commercial catch-per-unit-effort data.

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 most importantly the 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. The depletion of Deepwater Flathead in 2007 was estimated at 56%, and the unexploited female spawning biomass was estimated at 8,836t (Klaer, 2007).

The 2010 assessment (Klaer 2011a, b) included all available port and on-board collected length data combined. Following agreement by the RAG, the 2010 assessment included the FIS as a relative index for the first time. Unexploited female spawning biomass was estimated as 10,366t and current depletion at 62% of B0. The long-term RBC estimate was 1,137t. This assessment indicated that the stock had been more depleted than previously predicted in 2005/06, being down near the 20% B0 limit. Previous assessments had all indicated a stock in fish-down, but always above the target biomass.

The Deepwater Flathead assessment was repeated again in 2012 (Klaer 2013a, b) with the base case estimating an unexploited spawning stock biomass of 8,921t and a depletion at that time of 39% of SSB_0. The 2013/14 recommended biological catch (RBC) under the 20:35:43 harvest control rule was 979t and the long-term yield (assuming average recruitment in the future) was 1,051 t.

Finally, the latest Deepwater Flathead assessment was conducted using data to the end of 2012/2013 (Klaer, 2014a, b). This estimated the unexploited spawning stock biomass of 9,320t and a depletion at the start of 2014/2015 of 45% of SSB_0. The 2014/15 recommended biological catch (RBC) under the 20:35:43 harvest control rule is 1,146t and the long-term yield (assuming average recruitment in the future) is 1,105 t (Table 16.1).

Table 16.1. A summary of previous stock assessment outcomes for Deepwater Flathead. 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 (prior to 2009 these are MSY estimates). The 1999 biomass estimate is of exploitable biomass while the rest reflect female spawning biomass.

Year	Authors	B0 (t)	Depletion	RBC (LTY) (t)
1999	Tilzey and Wise(1999)	~32,000	-	
2000	Wise and Tilzey(2000)	53,760		
2002	Wise and Tilzey	12,876		
2005	Wise and Klaer (2006)	20,418	>79%	(670)
2006	Klaer and Day (2007)	10,084	50	1,070 ()
2007	Klaer (2007)	8,841	56	1,524 ()
2010	Klaer (2011b)	10,366	62	1,463 (1,137)
2012	Klaer (2013b)	9,320	45	1,146 (1,105)

16.2.3 *Modifications to the previous assessment*

An initial base case was developed and presented to the GAB RAB on 3rd November 2016; this was used to describe the changes wrought on the previous assessment by the sequential addition of the new data now available (known as a bridging analysis) along with other structural changes.
The latest version of the SS3 software was applied (SS3.24z; Methot and Wetzel, 2013; Methot, 2015) and then an array of data updates were made, including some data streams that had not been used previously. Importantly, there has been a change in general advice with regard the emphasis to be placed on the indices of relative abundance (standardized commercial CPUE and the Trawl Survey indices; Francis, 2011) relative to that placed on the age and length composition data. This relates to

the proportional emphasis given to the different data streams available when fitting the model and, in this case, different arrangements can lead to different assessment outcomes in terms of estimates of female spawning biomass and depletion levels. There was also discussion in earlier GAB RAGs concerning the validity of the 2015/2016 trawl survey indices of relative abundance so especial attention was paid to the influence of including that single new data point into that time series. The bridging analysis therefore included the usual incremental addition of new data to the earlier assessment but included two extra final analyses where either all FIS related data was removed or only the final year's survey index was removed.

The changes are described in a set different manipulations and changes to the old assessment (Table 16.2).

Table 16.2. The 11 different analyses conducted as part of the bridging analysis that revised the assessment conducted in 2013 to the current assessment that includes all new available data. An alternative basecase analyses in which the data stream variances have been fully rebalanced except the FIS survey data for 2014/2015 was removed.

Title	Description
origbase24f	Repeat the assessment from 2013 using the original software version SS3.24f
origbas24z	Use the newer version of SS3 (SS3.24z) to test the effect of using new software.
newCatCE	Add catch and commercial CPUE to 2015/16.
newsurvCE	Add the latest 2015/16 survey CPUE (a single new data point)
newRecs	Extend estimation of recruitment deviates from 2009 to 2012, and accept the recruitment bias adjustments suggested by SS3.
newLenComp	Include new length composition data – separate data from ISMP Port and on-board samples, and from Industry length composition data.
newAAL	Include new conditional age-at-length data for 2013 - 2015
ageingerror	Include a newly revised ageing error matrix
LenAgeFIS	Include FIS length composition data and age-at-length data and estimate the FIS selectivity
balancedCE	Re-balanced variances, with emphasis placed on CPUE and Survey
balnoFIS1415	Re-balanced variances, removing only the 2014/2015 survey index.

As adding significant amounts of new data can disturb the balance between different data sets and thus disturb the apparent mode outcomes (depletion estimation, etc) some rebalancing of the variances of the different data streams was conducted at each stage. At the final stage the variance of the different length and age composition data and the CPUE data were balanced until they all reached equilibrium 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 temporarily increasing the maximum recruitment variation from 0.5 to 0.55 for the four steps 'newLenComp', 'newAAL', 'ageingerror', and 'LenAgeFIS' as further bias adjustments were required after adjusting the variance estimates on different data streams. However, for the final 'balancedCE' basecase the SigmaR (recruitment variation) was returned to the assumed 0.5.

16.2.3.1 Estimation of RBC and Long Term RBC

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 43%B_0 (Kompas *et al*., 2011).

Following the projections, 16 sensitivity analyses were conducted to provide a test of the structural assumptions made in the formulation of the assessment model.

16.3 Methods

16.3.1 The Data and Model Inputs

16.3.1.1 Biological Parameters

Male and female Deepwater Flathead are assumed to have the same biological parameters except for their growth and the length-weight relationship (Table 16.3).

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; all male growth parameters are fitted as offsets to the female parameters. Fitting growth within the assessment model 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 0.235; the model outcomes are sensitive to this parameter and 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 about 40 cm. Changing the size at maturity has almost no effect on the quality of the model fit but has an 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 Deepwater Flathead comes from a single trawl fleet; although there is now a Danish seine vessel operating and some pair-trawling occurring in the GAB (Table 16.4).

Table 16.3. Summary of selected parameters from the base case model for Deepwater Flathead. 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. Years represent the first year of each financial year i.e. 2015 = 2015/2016.

Description	Source	Parameter	Combined Male/Female	
Years		y	1988-2015	
Recruitment Deviates		r	estimated 1980 - 2012	
Fleets			1 trawl only	
Discards			none significant, not Fitted	
Age classes		a	0 – 29 years	
Sex ratio		p_s	0.5 (1:1)	
Natural mortality		M	estimated (0.235) per year	
Steepness		h	0.75	
Recruitment variation		σ_r	0.55	
Female maturity	1		40 cm (TL)	
Growth	2	L_{max}	65.0258 cm (TL)	fitted
		K	fitted	fitted
		L_{min}	fitted	fitted
		CV	Fitted (M & F assumed equal)	
			Female	Male
Length-weight (based	3	f_1	0.002 cm (TL)/gm	0.002
on standard length)		f_2	3.332	3.339

16.3.1.2 Available Data

An array of different data sources are available for the Deepwater Flathead 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 four sources: the ISMP (keeping port sampling separate from the on-board sampling), from the FIS, and from on-board crew sampling (Figure 16.1). 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.

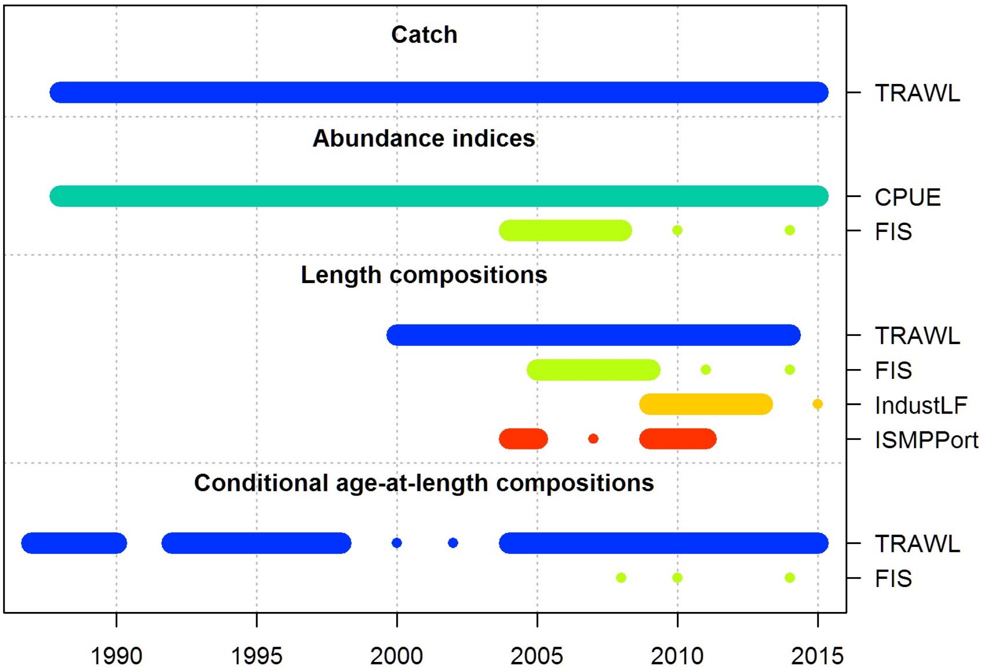


Figure 16.1. Data availability by type and year. The year axis denotes the first year of the financial year, thus 1995 = 1995/1996. This illustrates the full data set as used in the balancedCE basecase scenario.

A landed catch history for Deepwater Flathead is available for the years from 1988/1989 to 2015/2016 (Figure 16.2; Table 16.4). 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 all figures, where single years are illustrated these represent the first year of the 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 16.4).

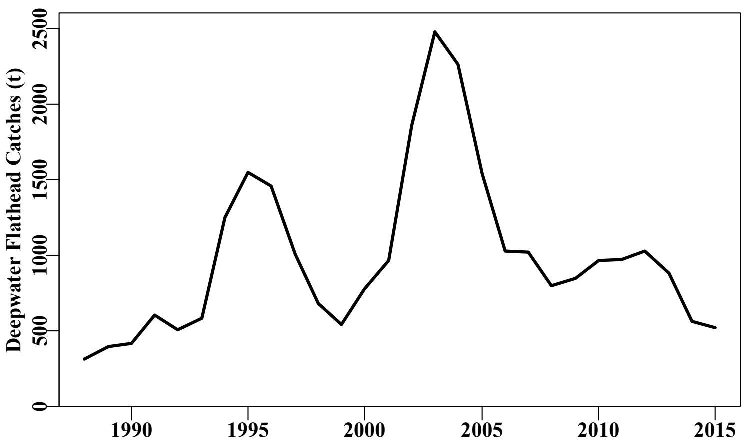


Figure 16.2. Total reported landed catch of Deepwater Flathead 1988/1989 – 2015/2016 (the final year's data is incomplete; see Table 16.4).

Table 16.4. Financial year values and estimates of catch by method, total catch, the geometric mean CPUE, the standardized Trawl CPUE, and the number of trawl vessels reporting Deepwater Flathead in the GAB from 1988/1989 – 2015/2016. Discards are assumed to be trivial. Standardized CPUE is from Sporcic and Haddon (2016), scaled to 88/89 – 15/16.

Season	DS	PTB	TDO	TW	Total	GeoMetric	Stand	Vessels	Records
88/89				316.559	316.559	56.081	0.9390	9	815
89/90				400.852	400.852	53.036	0.9633	7	1126
90/91				429.221	429.221	49.078	1.0404	11	1501
91/92				618.749	618.749	54.539	0.9522	13	1781
92/93				523.312	523.312	76.925	1.2104	4	984
93/94				591.010	591.010	91.500	1.5531	7	900
94/95				1266.045	1266.045	106.306	1.9671	6	1745
95/96				1574.134	1574.134	125.214	1.9094	5	1862
96/97				1475.916	1475.916	79.393	1.2654	8	2784
97/98				1017.668	1017.668	50.970	0.8971	10	2908
98/99				684.414	684.414	34.670	0.6678	7	2558
99/00				555.256	555.256	39.132	0.8121	7	2102
00/01				782.697	782.697	43.041	0.8781	6	2413
01/02				917.556	917.556	51.543	1.0460	6	2448
02/03				1657.349	1657.349	73.410	1.5175	8	3144
03/04				2235.568	2235.568	68.417	1.4288	10	4536
04/05				2111.130	2111.130	55.052	1.1513	10	5551
05/06				1378.191	1378.191	37.523	0.7493	11	5349
06/07				983.135	983.135	32.929	0.6430	11	4254
07/08				980.210	980.210	35.905	0.7236	7	4003
08/09				783.241	783.241	40.697	0.8516	5	3118
09/10				834.012	834.012	39.135	0.8012	4	3205
10/11	5.303		24.529	910.447	940.279	50.886	1.0292	4	2805
11/12	136.677		621.692	172.010	930.379	38.545	0.7888	4	3270
12/13	103.493		514.951	368.480	986.924	37.941	0.7753	5	3611
13/14	83.771	11.090	456.954	220.269	772.084	31.993	0.6695	7	3304
14/15	61.376		478.565	23.594	563.535	29.335	0.6183	4	2572
15/16	79.353		380.044	14.040	473.437	34.376	0.6832	3	996

16.3.1.3 Catch Rate Indices

In earlier assessments, 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; Sporcic and Haddon, 2016) and Deepwater Flathead is now included in the list of species routinely 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). In 1987/1988 over 95% of catches were taken in zone 82 and there were only 453 records so that year was also omitted.

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 16.5). It is recommended that the depth range used in the standardization should be reduced at least to 0 – 500m in future analyses.

Table 16.5. The number of records and catch reported by different depth categories. Approximately 8.315 t of catch has ever been reported from below 1000m across the duration of the fishery, and 20.433 t has ever been reported from depths greater than 500m.

Depth	Records	Catch	Cum%	Depth	Records	Catch
0	21	6.559	0.025	0	33	9.23
25	12	2.671	0.035	50	208	52.171
50	53	7.134	0.062	100	55515	18741.84
75	155	45.037	0.234	150	17973	6147.604
100	9815	2907.111	11.324	200	2672	922.5073
125	45700	15834.724	71.730	250	1091	270.145
150	14805	5253.466	91.771	300	377	34.8415
175	3168	894.139	95.182	350	179	8.0765
200	1764	585.957	97.417	400	93	5.20965
225	908	336.551	98.701	450	27	1.315
250	712	188.916	99.422	500	15	1.11775
275	379	81.230	99.731	550	8	0.432
300	279	29.089	99.842	600	9	1.35525
325	98	5.753	99.864	650	3	0.496
350	140	6.725	99.890	700	6	2.47
375	39	1.352	99.895	750	3	0.276
400	83	3.945	99.910	800	2	3.66
425	10	1.265	99.915	850	2	2.24
450	23	1.226	99.920	900	3	0.2985
475	4	0.090	99.920	950	1	0.18
500	13	0.538	99.922	1000	1	0.13

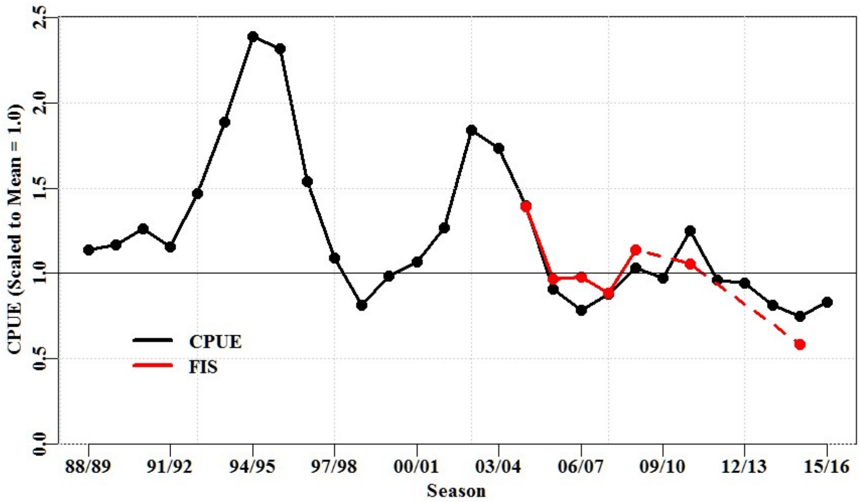


Figure 16.3. The standardized CPUE for Deepwater Flathead from the trawl fishery in the GAB (data from Sporcic and Haddon, 2016, p 183) with the index of relative abundance from the Fishery Independent Survey. Both time-series have been scaled so that over the years of the survey indices the mean of both series is 1.0 to make them directly comparable (see **Error! Reference source not found.** and **Error! Reference source not found.**). Note the most recent survey index is exceptionally low.

16.3.1.4 Fishery Independent Survey Abundance Estimates

There are now seven estimates of relative abundance from the Fishery Independent trawl Survey (Table 16.6; Knuckey, *et al*., 2015). The CV estimates for the individual abundance estimates are used initially, but in the process of balancing the output variability with that input, these values were greatly expanded. The last estimate for the season conducted in 2015 is the lowest estimate ever and only uses the samples taken in the second trip (Knuckey et al, (2015). The sampling on the first trip may have been compromised by a large scale acoustic survey that occurred at the same time. It is unknown whether the sampling for relative abundance during second trip was also compromised. The effect of including this single new point is explored in two runs of the bridging analysis, which focussed attention solely on the effect of this single survey (Table 16.2; see newsurvCE and balnoFIS1415).

Table 16.6. FIS relative abundance estimates for Deepwater Flathead, with each survey estimate's coefficient of variation (taken from Knuckey *et al*., (2015). The 2014/2015 estimate only uses the results from trip two so as to avoid the potential for interference from a proximate seismic acoustic survey.

Year	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2010/2011	2014/2015
Estimate	12,152	8,415	8,540	7,725	9,942	9,227	5,065
CV	0.05	0.06	0.05	0.06	0.05	0.05	0.09

16.3.1.5 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).

Since about 2000/2001 the proportion of older fish in the ISMP samples has declined (Figure 16.4) although they appear to be noticeably returning since about 2012/2013. A comparison of the age composition seen in the FIS years and the ISMP samples from the same financial year (Figure 16.5) suggests similarities although it is clear that the FIS samples have a lower mean age than those from the ISMP. The difference inmean age reflects the different selectivity of the gear used to collect the FIS samples relative to that of the whole fleet from which the ISMP samples were collected (Figure 16.4, Figure 16.5; Table 16.7).

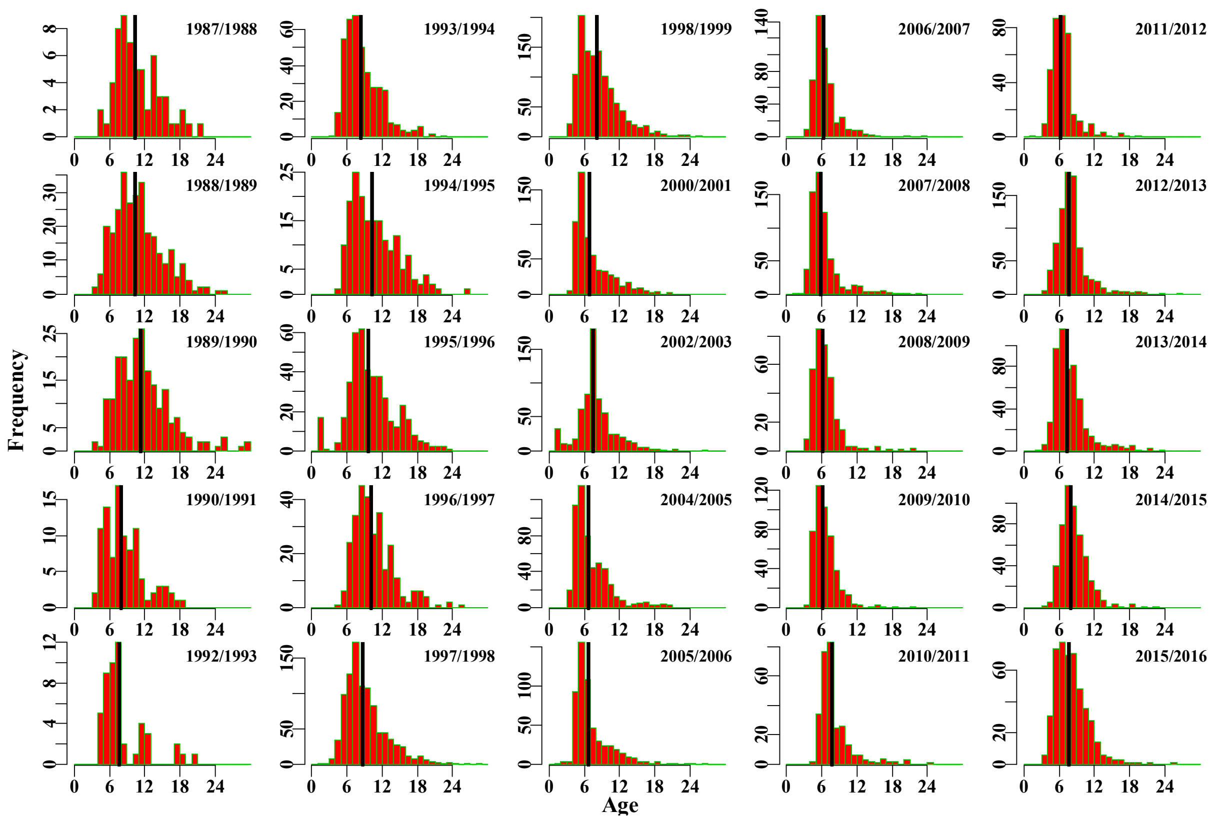


Figure 16.4. All ISMP Deepwater Flathead ageing data used by year, illustrating the relative sample size and the relatively recent contraction in the older age classes. (see Table 16.7).

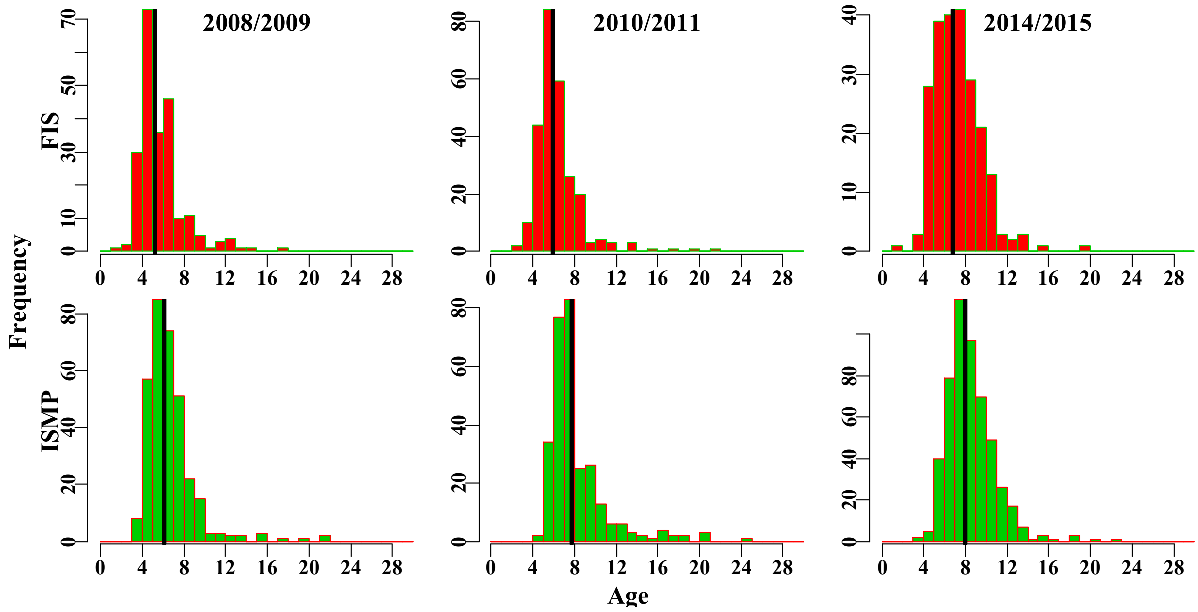


Figure 16.5. All ISMP Deepwater Flathead ageing data used by year, illustrating the relative sample size and the relatively recent contraction in the older age classes. (see Table 16.7).

Table 16.7. The mean age and number of observations of each season's ageing data from the ISMP sampling and the sampling during the FIS, as used in the Deepwater Flathead assessment.

Season	ISMP Mean Age	ISMP Nobs	Season	ISMP Mean Age	ISMP Nobs	FIS Mean Age	FIS Nobs
1987/1988	10.34	61	2004/2005	6.67	563		
1988/1989	10.42	290	2005/2006	6.73	555		
1989/1990	11.28	214	2006/2007	6.28	484		
1990/1991	8.03	97	2007/2008	5.87	650		
1992/1993	7.74	50	2008/2009	6.16	329	5.25	225
1993/1994	8.30	407	2009/2010	6.16	465		
1994/1995	10.24	178	2010/2011	7.67	290	5.87	262
1995/1996	9.66	430	2011/2012	6.26	367		
1996/1997	10.07	287	2012/2013	7.61	787		
1997/1998	8.77	972	2013/2014	7.36	528		
1998/1999	8.06	1163	2014/2015	8.03	519	6.78	225
2000/2001	6.88	600	2015/2016	7.63	478		
2002/2003	7.48	640					

16.3.1.6 Length Composition Data

Previously (Klaer, 2012), only used length composition data from the ISMP, and port and on-board samples were considered together, which was standard practice at the time. 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 16.1). Separating the on-board and ISMP samples makes explicit the fact that port based samples are often of sorted (or graded) samples. In Deepwater Flathead there are only two grades 'All' and 'Unk', with 'All' dominating in numbers. Mostly the sample weights were between 30 – 32 kg (the expected weight of a single fish bin full of fish). Currently the options for whether or not to apply catch weighting modified by grade data and or location data, to generate a combined length composition for each year in the context of changes in the sampling regime of the ISMP through time remains under investigation. This is not such an issue for Deepwater Flathead, which, by using 'All', appears to assume there has been no grading for landed fish. However, in some species, such as Western Gemfish there are numerous grades landed and how best to weight these data requires further exploration.

The crew collected length composition data exhibited consistent length composition data spread from across the fishery, however, an unusual and atypical distribution was exhibited by the sample from 2014/2015 and this was therefore omitted from consideration while the source of this deviation from the more typical composition was explored (Figure 16.6), however, the data from 2009/20110 to 2015/2016 were included using the same selectivity as for the ISMP data. The anomalous data may be a result of sampling is shallower water than normal, or may be due to a measurement error.

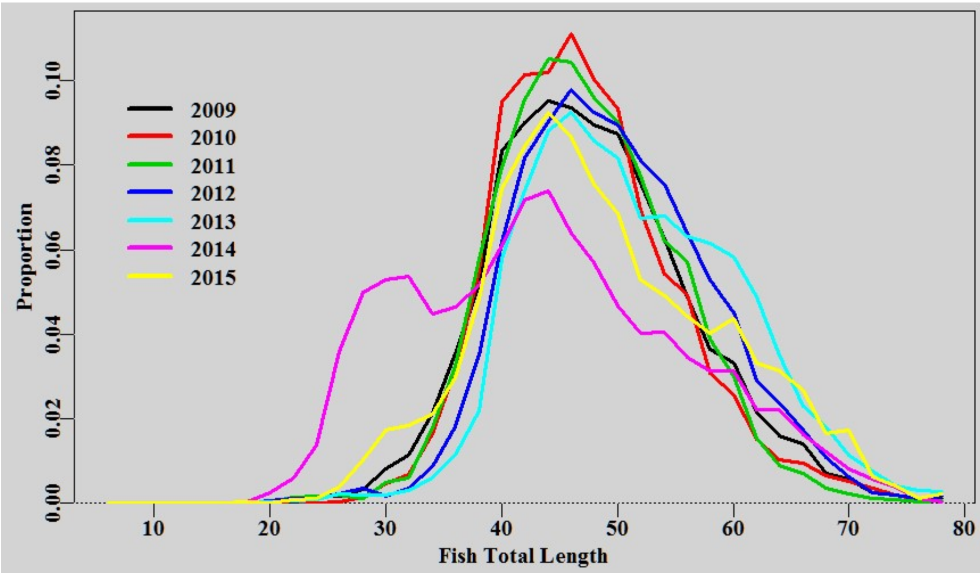


Figure 16.6. Length composition data for Deepwater Flathead obtained from crew sampling on-board. The data for 2014/2015 was exceptional and constituted a sample size only 3/5th the usual samples size. It unusual form led to it being omitted from consideration prior to discussion in the November 2016 GAB RAG meeting, and further analyses attempting to explain its anomalous shape.

The length composition data from the FIS also exhibits variation through time (Figure 16.7) with some large changes between 2010/2011 and 2014/2015.

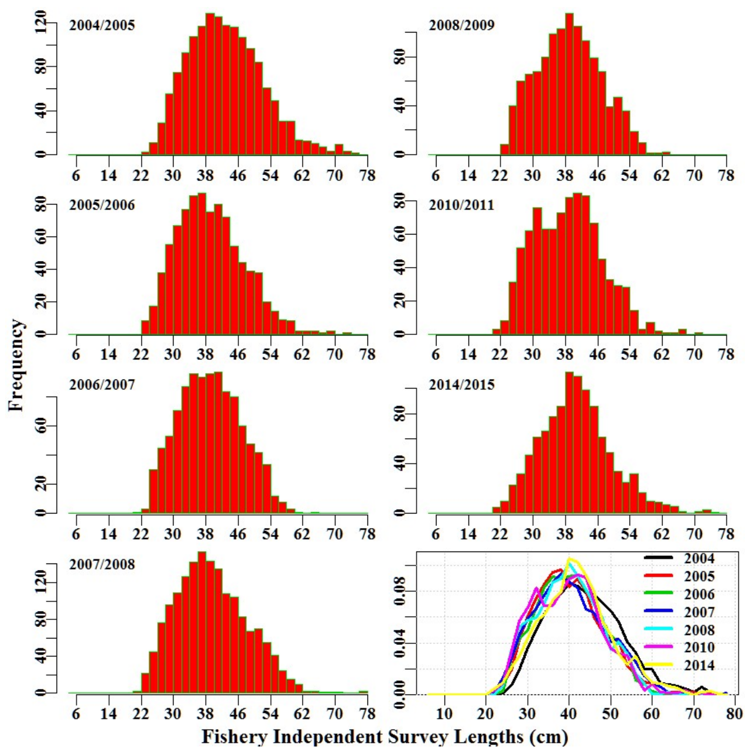


Figure 16.7. The length composition data of Deepwater Flathead from the seven FIS that have occurred in the GAB. The plot at bottom right illustrates the contrast between years, with the legend showing only the first year of the season.

The length composition data from the ISMP also varies considerably from year to year in both the on-board and port data (Figure 16.8, Figure 16.9).

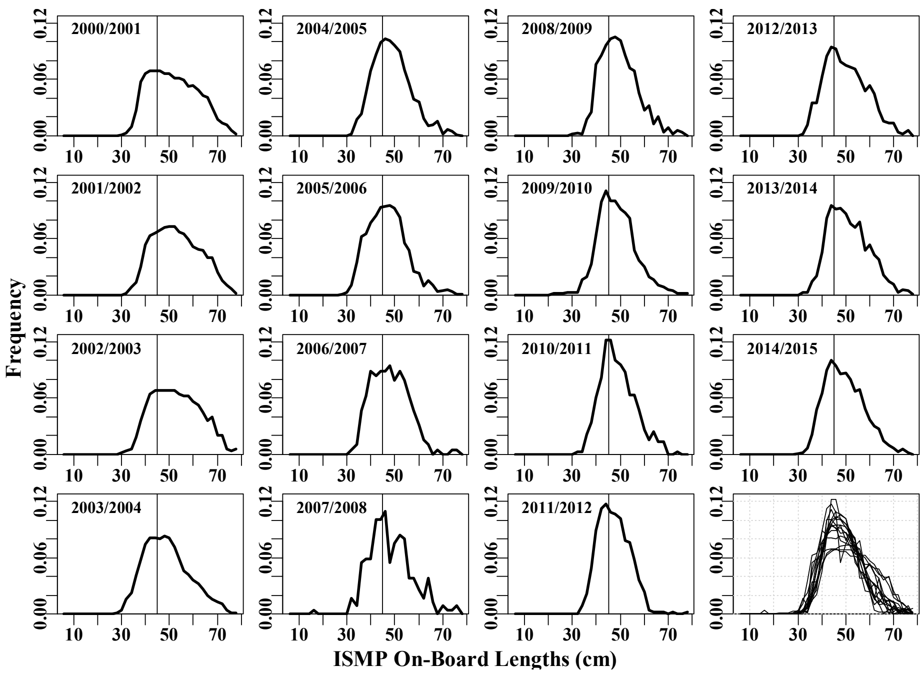


Figure 16.8. The proportional distribution of on-board length composition data for Deepwater Flathead from the ISMP. The vertical grey line at 45cm is to ease visual comparisons. The plot at bottom right is a combination of all the plots to illustrate the variation between years.

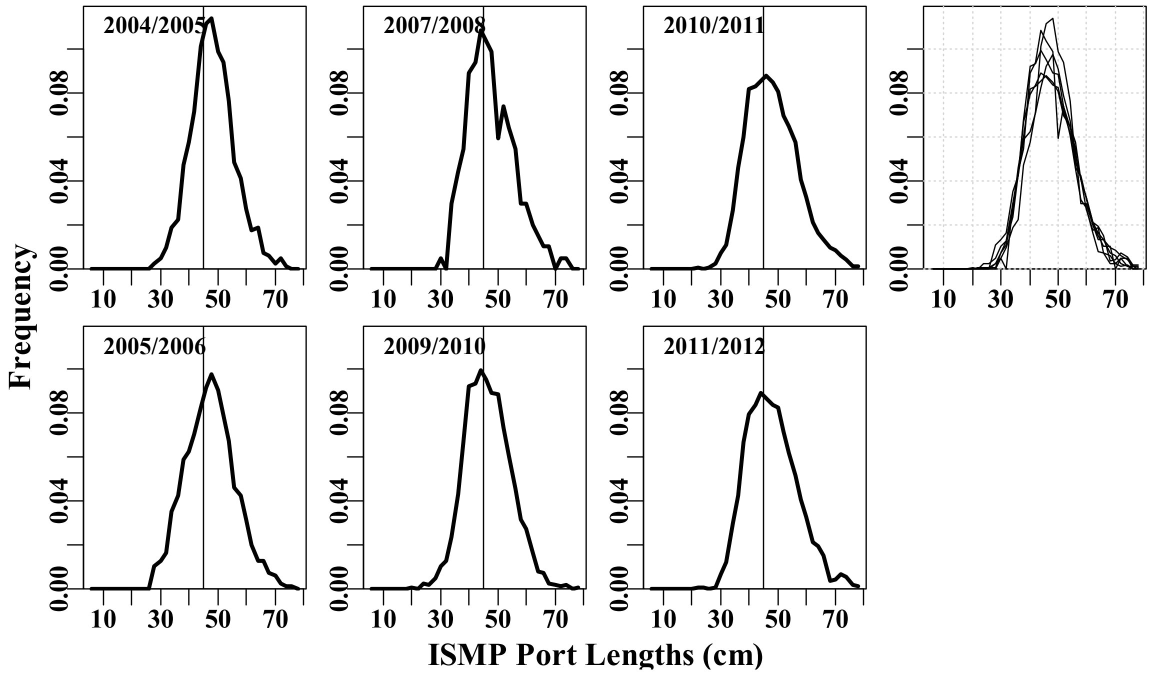


Figure 16.9. The proportional distribution of Port sampled length composition data for Deepwater Flathead from the ISMP. The vertical grey line at 45cm is to ease visual comparisons. The plot at bottom right is a combination of all the plots to illustrate the variation between years.

Table 16.8. Original sample sizes for the length and age composition data for Deepwater Flathead. There were thus four length composition data streams and two age composition data streams. Note the very large sample sizes from the Industry sampling.

Season	ISMP Ages	Season	ISMP Ages	FIS Ages	ISMP On-Board	ISMP Port	FIS LF	Industry LF
1987/1988	61	2000/2001	600		1867			
1988/1989	290	2001/2002			1467			
1989/1990	214	2002/2003	640		496			
1990/1991	97	2003/2004			715			
1991/1992		2004/2005	563		1009	854	1495	
1992/1993	50	2005/2006	555		1125	851	897	
1993/1994	407	2006/2007	484		191		1046	
1994/1995	178	2007/2008	650		238	203	1635	
1995/1996	430	2008/2009	329	225	750		1140	
1996/1997	287	2009/2010	465		676	2507		5957
1997/1998	972	2010/2011	290	262	378	3339	915	5931
1998/1999	1163	2011/2012	367		471	4647		5376
1999/2000		2012/2013	787		522			5645
		2013/2014	528		846			5047
		2014/2015	519	225	1269		1074	3336
		2015/2016	478					8361

16.3.1.7 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 4.

Table 16.9. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes of Deepwater Flathead.

Age	StDev.	Age	StDev.	Age	StDev.
0	0.2017	10	0.5495	20	0.6594
1	0.2570	11	0.5669	21	0.6650
2	0.3063	12	0.5825	22	0.6699
3	0.3502	13	0.5964	23	0.6743
4	0.3894	14	0.6088	24	0.6782
5	0.4243	15	0.6198	25	0.6817
6	0.4554	16	0.6297	26	0.6817
7	0.4831	17	0.6385	27	0.6817
8	0.5078	18	0.6463	28	0.6817
9	0.5298	19	0.6532	29	0.6817

16.3.2 ***Stock Assessment***

16.3.2.1 Population Dynamics Model and Parameter Estimation

A two-sex stock assessment for Deepwater Flathead has been implemented using the software package Stock Synthesis (SS, version 3.24z; Methot and Wetzel, 2013). However, differences by gender are restricted to growth and weight at length. SS is a statistical age- and length-structured model that can be used to fit the various data streams now available for Deepwater Flathead, 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 Deepwater Flathead 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; although this might be questioned as more spatially explicit data is collected. The two parameters of the selectivity function were estimated within the assessment. Now that FIS length and age composition data are included as data streams a separate selectivity was able to be estimated for the FIS, and 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 1980/1981 to 2011/2012. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was set equal to 0.5 to begin with, it required to be extended to 0.55 during the addition of extra composition data, however, after complete balancing and recruitment deviate bias adjustment (Methot and Taylor, 2011) it again ended at 0.5. During the rebalancing of variances the model continued to suggest reducing the SigmaR value so it could have been reduced to 0.45 and well below, however, this would have constrained the recruitment variability implausibly and so the value was fixed at 0.5. The recruitment deviates for more recent years cannot be estimated well because it can take 3 – 4 years for larval fish to grow and then enter the fishery. Hence, it can take 4 years before information about relative recruitment levels becomes available to the model.

Age 29 is treated as a plus group into which all animals predicted to survive to ages greater than 29 are accumulated. Growth of Deepwater Flathead was also assumed to be time-invariant, that is there has been no change over time in the expected 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 16.9). Differences in growth by sex were in terms of both the L_∞ and the *K* parameters of the von Bertalanffy curve and the length-weight relationship.

16.3.2.2 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 or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size was equal to the effective sample size calculated by the model.
An automated tuning procedure was used0:

1. Set the CV for the commercial CPUE values and the FIS values to 0.1 for all years (this relatively low value is used to encourage a good fit to the abundance data).

Then iterate through the following:

2. Adjust the recruitment variance (σ_R) by replacing it with the RMSE or a defnied set minimum (in this case 0.5) and iterating to convergence (keep altering the recruitment bias adjustment ramps appropriately at the same time).
3. Simultaneously tune the sample size multipliers for the length frequencies and age at length using Francis weights for the LFs and Francis B (the larger of the Francis A and B factors, Francis 2011).
4. Weight the commercial CPUE and FIS abundance indices by replacing these with the relevant variance adjustment factors derived from SS3.
5. Repeat steps 2 to 4, until all are converged and stable.

This procedure may change in the future.

16.3.2.3 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) Deepwater Flathead 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}: $B_{Inflection\ point}$: F_{targ}) strategy. An economic analysis was used as a basis for using a 20:35:43 rule for Deepwater Flathead (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 43%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 43%B_0 is achieved and citing that final catch level.

16.3.2.4 The Development of the Base-Case Assessment

Eleven sequential changes were made to the 2013 assessment (Table 16.2). It was possible to closely match the original assessment spawning biomass time-series (Klaer, 2014a, b) using the SS3.24f version and there was almost no difference to the outcome when the latest version of SS3 (SS3.24z) was used.

Table 16.10. The 11 sequential changes made to the 2013 assessment model. The final base-case is either the balancedCE or balnoFIS1415 models (see Table 16.2).

N	Name	Description
1	origbase24f	Repeat the assessment from 2013 using the original software version SS3.24f
2	origbas24z	Use the newer version of SS3 (SS3.24z) to test the effect of using new software.
3	newCatCE	Add catch and commercial CPUE to 2015/16.
4	newsurvCE	Add the latest 2015/16 survey CPUE (a single new data point)
5	newRecs	Extend estimation of recruitment deviates from 2009 to 2012, and accept the recruitment bias adjustments suggested by SS3.
6	newLenComp	Include new length composition data – separate data from ISMP Port and on-board samples, and from Industry length composition data.
7	newAAL	Include new conditional age-at-length data for 2013 - 2015
8	ageingerror	Include a newly revised ageing error matrix
9	LenAgeFIS	Include FIS length composition data and age-at-length data and estimate the FIS selectivity
10	balancedCE	Re-balanced variances, with emphasis placed on CPUE and Survey
11	balnoFIS1415	Re-balanced variances, removing only the 2014/2015 survey index.

16.3.2.5 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 16.11). In addition, the assessment outcomes were sensitive to the value of natural mortality, so a further likelihood profile (Venzon and Moolgavkar, 1988) was made for that parameter.

Table 16.11. Changes used to test the model's sensitivity to modified assumptions and data inputs.

1.	$M = 0.141\ yr^{-1}$. (relative to the base-case model estimate of 0.191)
2.	$M = 0.241\ yr^{-1}$
3.	50% maturity at 35cm. (relative to that assumed in the model of 40cm)
4.	50% maturity at 45 cm.
5.	σ_R set to 0.4 (relative to that assumed in the model of 0.5)
6.	σ_R set to 0.6
7.	Double the weighting on the length composition data.
8.	Halve the weighting on the length composition data.
9.	Double the weighting on the age-at-length data.
10.	Halve the weighting on the age-at-length data.
11.	Double the weighting on the abundance (CPUE) data.
12.	Halve the weighting on the abundance (CPUE) data.
13.	Derive the RBC using the 20:35:48 harvest control rule, rather than the 20:35:43. This is not a sensitivity on the assessment but on the forecast RBC values.
14.	Fix steepness (h) at 0.65 (relative to model assumed 0.75)
15.	Fix steepness (h) at 0.85
16.	No Survey Data (remove all FIS index, age- and length-composition data)

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 16.16):

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

16.4 Results and Discussion

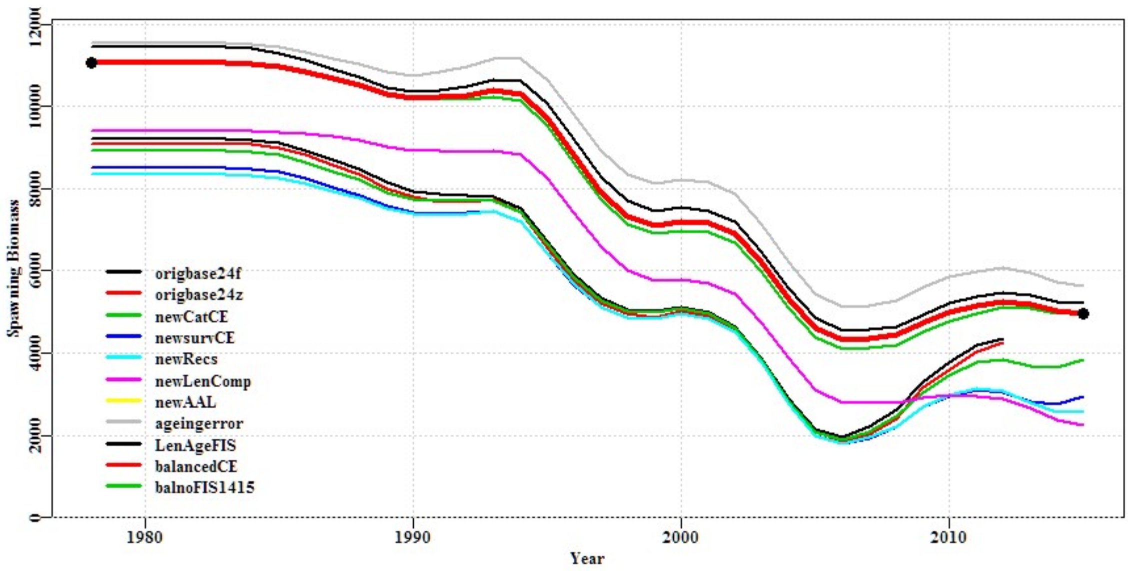
16.4.1 *The Base-Case Analysis*

Stepping sequentially through the different scenarios leading from the 2013 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. Generally this occurred because the addition of new data meant the balance between variances and effective sample sizes as well as the recruitment bias adjustments became badly out of balance. BY conducting a limited variance rebalance then the effect of adding the extra data could become more clear. The trend of reducing biomass reversed with the final balancing of variances between the data streams and adjustment of the recruitment bias adjustment and variation of recruitment deviates (balancedCE). While the final estimated female unfished spawning biomass was 11,046 t relative to 9,320 t in 2013, the spawning biomass depletion level was essentially the same at 0.45 which was nearly identical with the 0.45 in 2013 (Table 16.1 and Table 16.12). With the addition of large numbers of new samples (the Industry LF samples alone contribute more than 35,000 extra records; Table 16.8) and the sub-division of both the length and ageing data into their component parts the imbalance with the relative weights attributed to the different data streams became extreme. For this reason some limited rebalancing started with the newLenComp scenario so as to obtain more sensible and more comparable results (Table 16.12).

Table 16.12. The spawning biomass (B0), at the end of 2015/2016, with the spawning biomass depletion (Depl), and the natural mortality estimate (M) obtained during the development of the 2015/2016 variance balanced base-case assessment for Deepwater Flathead. The four right-hand columns relate to the likelihood contributions from the Indices (both the commercial CPUE and the FIS abundance index), AgeComp relates to the conditional Age at Length data for the ISMP onboard, the Port, the Industry sampling, and the FIS, the LenComp includes the ISMP onboard, ISMP Port, Industry LF samples, and the FIS LF samples, finally Recruit is the contribution from the recruitment residuals. The final year of estimating recruitment residuals increased from 2008 to 2011 in the newRecs scenario. SigmaR needed to increase from 0.5 to 0.55 with the newAAL scenario and then returned to 0.5 for the balancedCE The inclusion of the FIS ageing and length composition data began with LenAgeFIS.

Scenario	B0	Depl	M	Indices	AgeComp	LenComp	Recruit
origbase24f	9201	0.474	0.236	-17.43	333.71	214.87	-10.18
origbase24z	9067	0.471	0.236	-17.44	333.73	214.88	-10.14
newCatCE	8921	0.432	0.234	-19.02	334.11	215.37	-10.01
newsurvCE	8502	0.348	0.228	-15.96	334.88	217.05	-9.98
newRecs	8330	0.313	0.228	-17.35	334.50	216.96	-10.02
newLenComp	9390	0.240	0.165	-21.80	246.45	76.82	-7.11
newAAL	11534	0.489	0.191	-29.30	178.05	45.77	-4.15
ageingerror	11534	0.489	0.191	-29.30	178.05	45.77	-4.15
LenAgeFIS	11439	0.456	0.198	-27.89	231.49	71.05	-9.77
balancedCE	11046	0.450	0.191	-27.52	290.23	84.68	-10.46
balnoFIS1415	11069	0.451	0.187	-29.66	289.05	86.01	-10.72

The addition of new composition data and the rebalancing led to improvements (likelihoods getting smaller) in the fitting to all data streams. Importantly, the estimate of natural mortality declined once the new composition data was added, which in turn led to the increase in unfished biomass (Table 16.12).



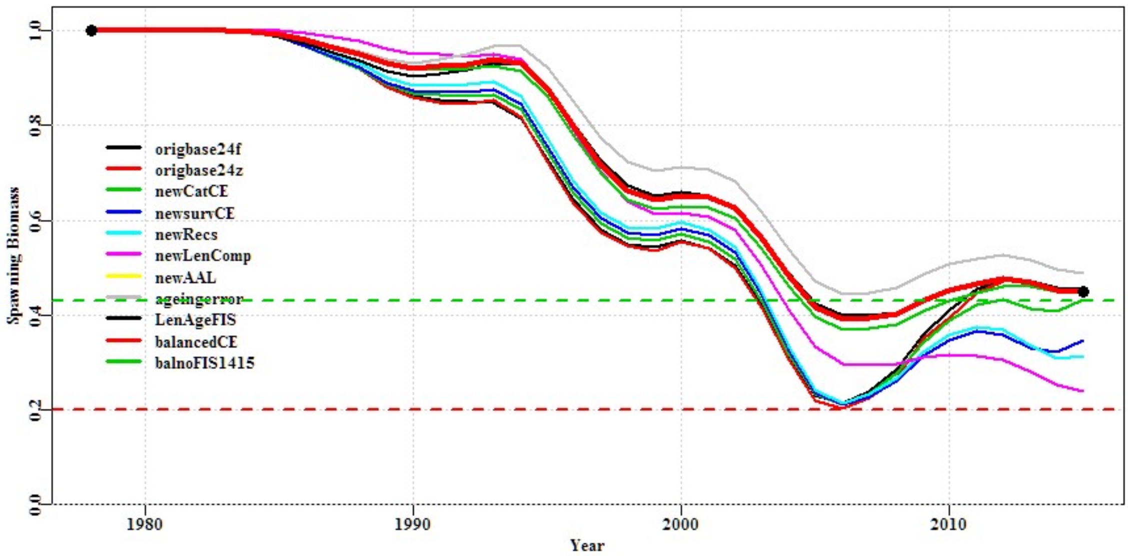


Figure 16.10. The predicted female spawning biomass and relative depletion level for the main scenarios describing the inclusion of different data and alternative assessment software. Some lines sit almost exactly on top of each other (for example the origbase24f and origbase24z), the thicker red line with the black dots is the balanced outcome from the base-case (see Table 16.10 for an explanation of each scenario).

Despite catches being relatively low recently (Table 16.4; Figure 16.3) the estimated spawning biomass trajectory suggests a very gradual decline since 2012/2013. It remains, however, just (2%) above the target reference point for spawning biomass depletion.

An alternative base-case was considered which removed the final index of abundance from the FIS data series. This retained the length and age composition data from the FIS plus the first six FIS indices of abundance while only removing the final, possibly compromised index from the 2014/2015 survey (Figure 16.11). Given that only a single data point has been removed the impact of that single point altered the likelihood for the indices and the length composition data but had little effect on the final biomass depletion level (Table 16.12). The predicted trajectory followed by the stock is very similar to that of the balancedCE scenario that includes the final FIS data point.

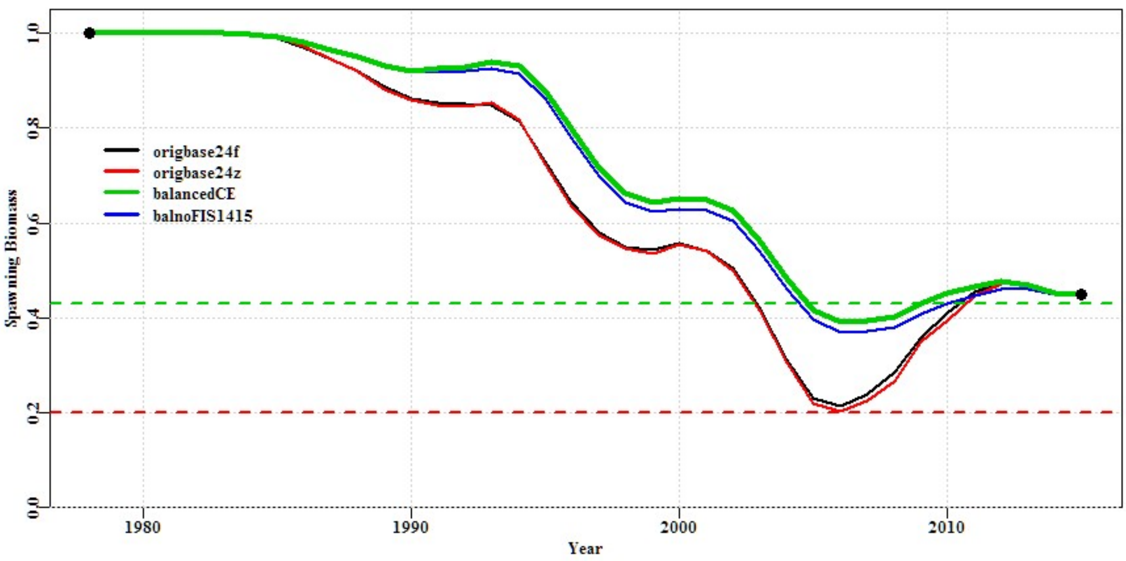


Figure 16.11. The predicted female spawning biomass depletion level for Deepwater Flathead comparing the final two balanced base-case candidates with the original assessment outcome from 2013. The optimum here is the thicker green line.

The November 2016 RAG considered the two alternative basecase scenarios and accepted that even though the final FIS relative abundance index was the lowest ever, and possibly biased, it was within the range of previous variation and had very little effect against the weight of other data included in the assessment. The expectation is that if there is another survey then the outcome would help correct the trend of the FIS index. The conclusion was to accept the balencedCE as the basecase scenario and proceed with the sensitivities based on that.

16.4.2 *Model Fits*

The estimated growth curve for female and male Deepwater Flathead is assumed to be the same (Figure 16.12). All growth parameters are estimated by the model except for L_{max} (Table 16.13). 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 16.12; Table 16.13). In addition to these results the different contributions to the total likelihood also provides insights into the relative fit (Table 16.12), although, not all scenarios are directly comparable because their different structures mean there are different numbers of parameters and the re-balancing also makes comparisons invalid.

Table 16.13. 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.	C.V.	Comment
Natural mortality *M*	0.191	0.0247	10.6	estimated
Recruitment				
σ_R	0.5			Fixed
deviates	1980 – 2011			estimated
Ln(R0)	8.9413	0.313	3.5	estimated
First bias adjustment	1962 – 2005			estimated
Final bias adjustment	2007 – 2017			estimated
maximum bias adjustment	0.8764			estimated
Growth				
CV	0.1414	0.0034	2.4	estimated
K	0.2354	0.0003	0.1	estimated
L_{min}	18.016	0.7364	8.4	estimated
L_{max}	65.0258			fixed
Selectivity				
Trawl L50	39.716	0.6823	1.7	estimated
Trawl inter-quartile	8.595	0.7076	8.2	estimated
FIS L50	29.093	0.6931	2.4	estimated
FIS inter-quartile	5.261	0.7572	14.4	estimated

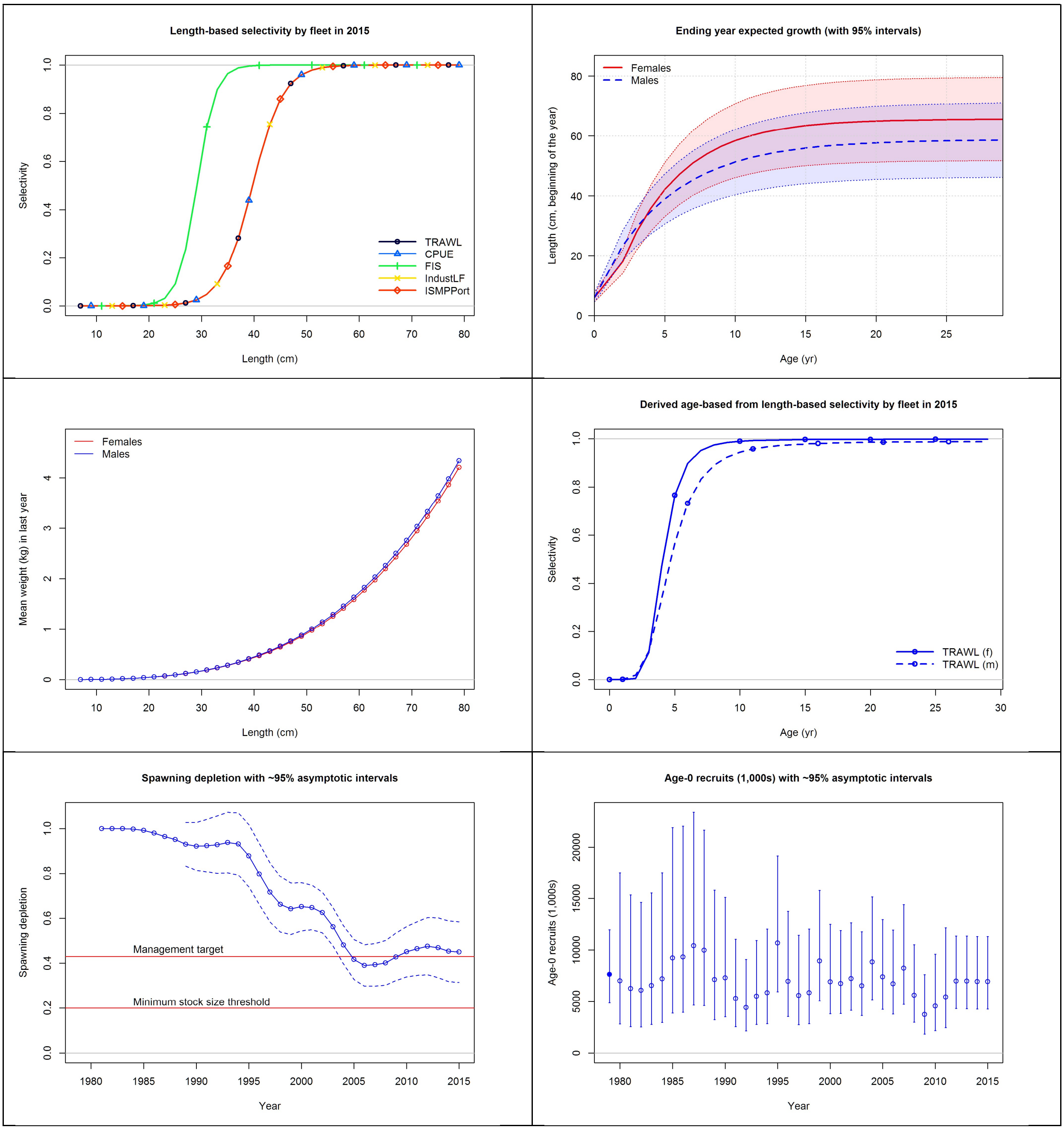


Figure 16.12. The selectivity curves for the trawl fishery and related length frequency data and of the FIS, and the predicted expected growth curves for females and males. The predicted mean weight at length, and derived age-based, length-based selectivity, the predicted depletion level of the balanced model with the 95% asymptotic confidence intervals, and the Age-0 recruit levels, again with the 95% asymptotic confidence intervals.

16.4.3 ***Fits to the Data***

16.4.3.1 CPUE Data

At first consideration the fits to the catch rate indices (Figure 16.13) appear reasonable with the predicted commercial CPUE trajectory reflecting the ups and downs of the full time series although with less dramatic changes in the predicted mean than observed in the fishery. The FIS relative abundance index essentially follows the same trend as the commercial CPUE until the very latest survey (Figure 16.3). Even with an expanded Coefficient of Variation during the rebalancing process it was not possible to fit the last data point in the FIS index without disrupting the relative fit of the FIS length and age composition data and the other composition data.

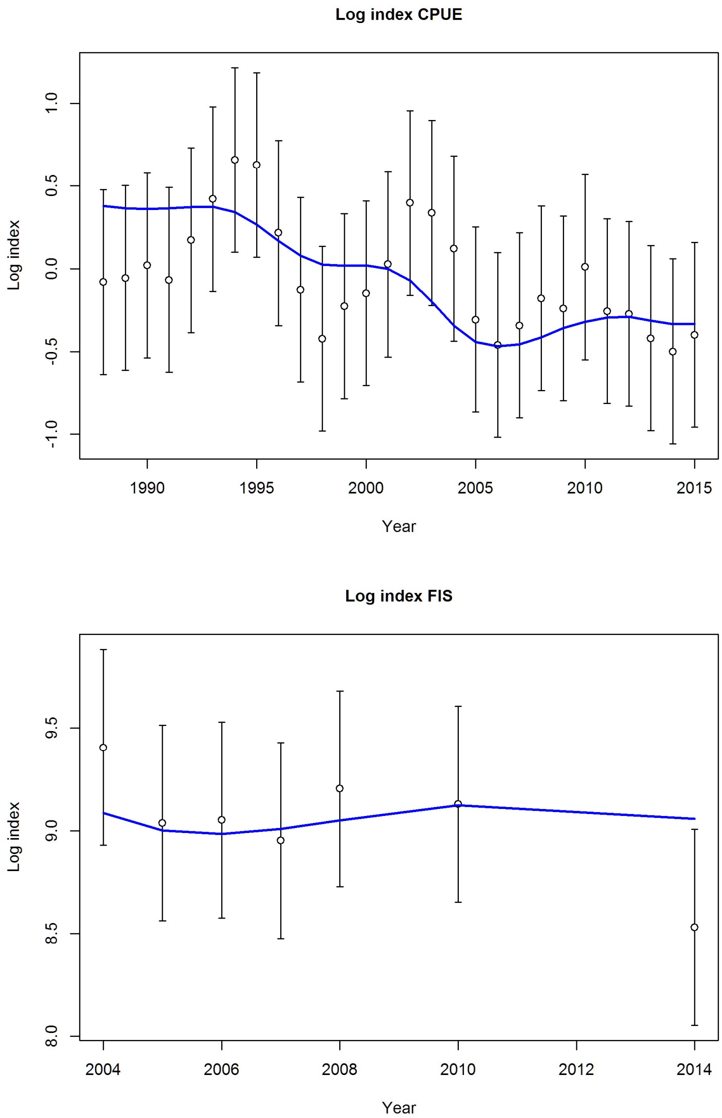


Figure 16.13. The balanced model fit to the commercial CPUE index of relative abundance and to the FIS index of relative abundance. Each year in the figures relates to the first year of each financial year combinations; e.g. 2001 = 2001/2002. The plots are of the natural Log Index because log-normal residual errors were used to fit the model to the abundance index data.

Such model fits are only relative to other possible fits. To illustrate this the model fit to CPUE and the FIS index for the current base-case (balancedCE) is compared with the equivalent model fits to the 2013 assessment and to the alternative base-case (balnoFIS1415). To make such a comparison valid each time-series of the observed and expected CPUE needed to be scaled to 1.0 over the years they had in common. Given that the 2013 assessment used commercial CPUE data from 1988/1989 - 2010/2011 and the FIS shared the years 2004/2005 – 2010/2011 in common, each of the three time-series were scaled to a mean of 1.0 over those years. Comparisons of the sum of their absolute residuals from the similarly scaled observed values were also calculated only for the years of overlap. In this way their relative fit could be ascertained both visually and quantitatively.

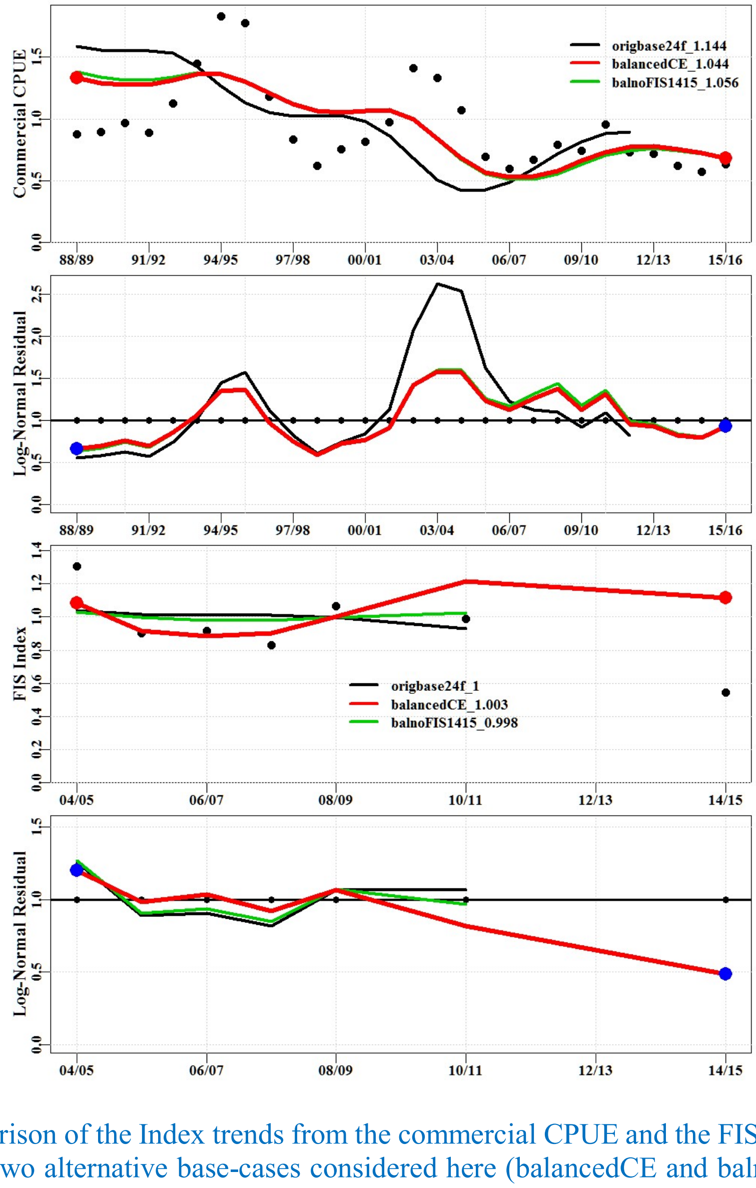


Figure 16.14. A comparison of the Index trends from the commercial CPUE and the FIS for the 2013 base-case (origbase24f) and the two alternative base-cases considered here (balancedCE and balnoFIS1415). Each time series is scaled to a mean of 1.0 over the years of overlap in each case. The numbers associated with each name in each legend are the mean log-normal residual between the expected and observed over the period of common overlap (closest to 1.0 is best). In the top panel balancedCE is closest to 1.0 while with the FIS index the 2013 mode was best over the 04/05 – 10/11 period but all are close and balanceCE follows the early trend better. The exceptional nature of the most recent estimate is clear.

The current approach used when fitting assessment models is to attempt to place emphasis on the relative index of abundance data (Francis, 2011). This is a major reason the quality of model fit to the different indices of relative abundance is better in the 2016 assessment than that in the 2013 assessment. The effect of omitting the final FIS index is only minor on the commercial CPUE (including it flattened the time-series slightly), but its effect on the fit to the FIS data is marked. It is also clear just how exceptional the last data point in the FIS is relative to all the other data in the assessment.

The commercial catch rates exhibit some relatively extreme variation through time. This reflects the changing conditions in the fishery, which has seen catches vary from about 500 t a year up to 1500t down again to 500 t, then up to nearly 2500 t, and then down to 1000t or less (Figure 16.2). Such changes are also reflected in the catch per vessel and in the number of vessels operating in the fishery (which has also been affected by the licence buyout associated with the structural adjustment during November 2005 to November 2006 (Figure 16.15).

Such changes may have contributed to the commercial CPUE exhibiting residual differences between the observed and expected CPUE with a distinct pattern of first being above the center line and then being below it (Figure 16.14). Such serial correlation demonstrates that some important factor has been missed in the standardization. The sequence of residuals lying either side of the expected in a pattern of up and down. In this case the pronounced negative residuals reflect the periods of greatly elevated catches (Figure 16.2), which suggests that fishing behaviour was considerably altered during these periods. Such behavioural changes are difficult to capture within a CPUE standardization.

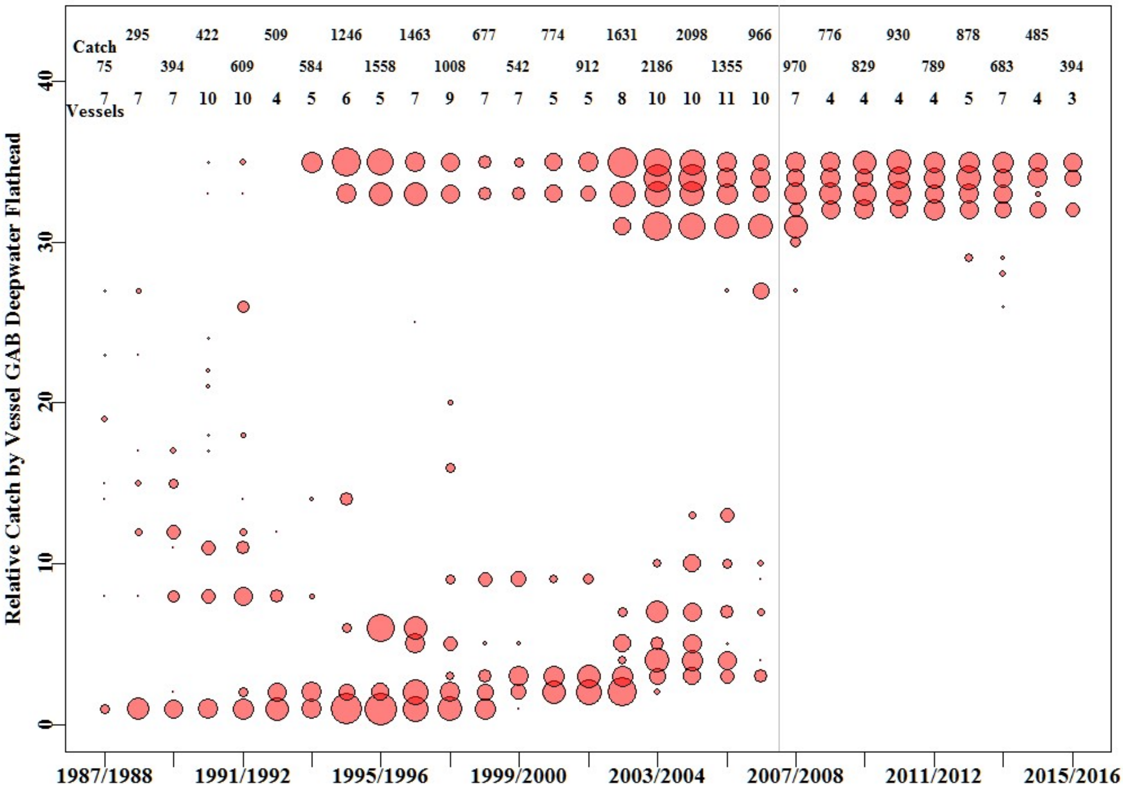


Figure 16.15. The relative catch (square root of catch) of Deepwater Flathead per trawl vessel in the GAB fishery, with the vertical line depicting the advent of the structural adjustment. The lowest of the top three lines lists the number of vessels reporting > 1 t across all years, and the other two lines are the reported catches, staggered to improve readability.

16.4.3.2 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 16.17) and this is reflected in their respective selectivity curves (Figure 16.12). Deepwater Flathead 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 16.12). 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 16.17), 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 16.17). Further illustrations of the relative fit to the length-composition data are provided in the Appendix.

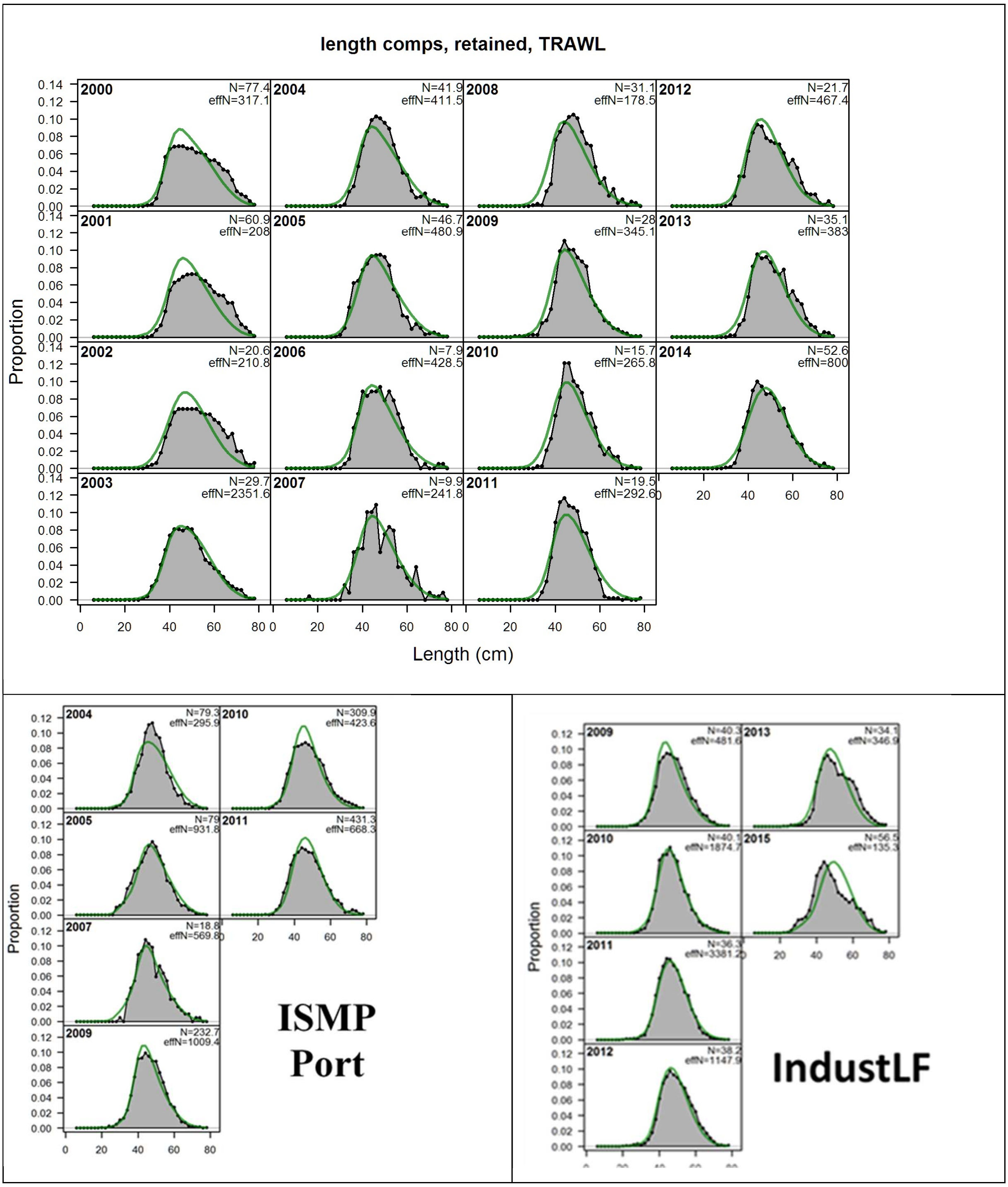


Figure 16.16. The base-case (balancedCE) fit to the ISMP collected length composition data from on-board. Numbers of observations in each case are listed in Table 16.8. The listed year relates to the first of the financial year pair. The samples from 2006/2007 and 2007/2008 were especially small, hence their spikiness.

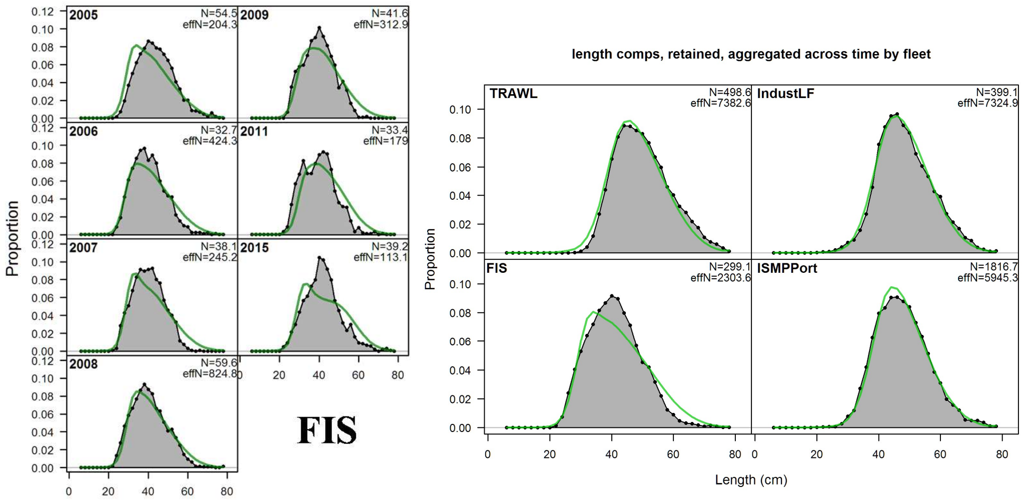


Figure 16.17. The base-case model fit to the different time-series of length-frequency composition data for the FIS data, the industry on-board data (industLF), the ISMP Port data, and the summary across years for each data set. Each year in the figures relates to the first of the financial year combinations; e.g. 2001 = 2001/2002.

16.4.4 *Base-Case Assessment Outcomes*

The stock depletion level at the end of 2015/2016 is estimated to be approximately 4,993 t or 45%B_0, (Figure 16.18), while the estimated, approximate MEY biomass level is 43%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 16.18). 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 lower than average predicted by the stock recruitment curve in the years 2007/2008 – 2011/2012 (Figure 16.19), although fish spawned in those years would only just have entered the fishery. In addition, recruitment levels are not particularly variable (Figure 16.19).

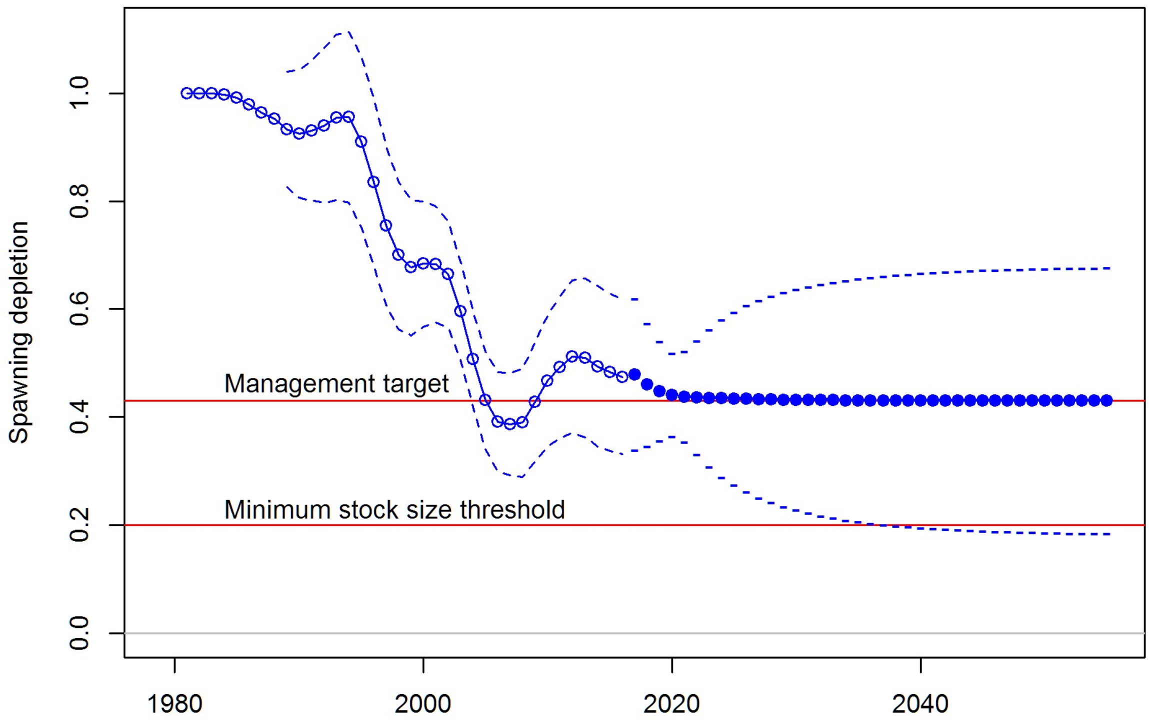


Figure 16.18. The trajectory of spawning stock depletion, including 40 years of projection used to estimate the current RBC and the long-term RBC. The stock only begins to decline slowly when fishing first begins and then accelerates downwards once catches reach about 800 – 1000t per year. With the more recent drop in catches from about 2009/2010, the stock is predicted to have increased to the present day until it ended at about 45%B_0 at the end of 2015/2016. If catches adhere to the predicted RBCs then it will take approximately 40 years for the stock to decline to the estimate MEY at 43%B_0.

The predicted trajectory in the 40 projections depends upon the estimated RBC being caught each year, which, given recent catches and reports of difficulty in catching the fish, seems unlikely.

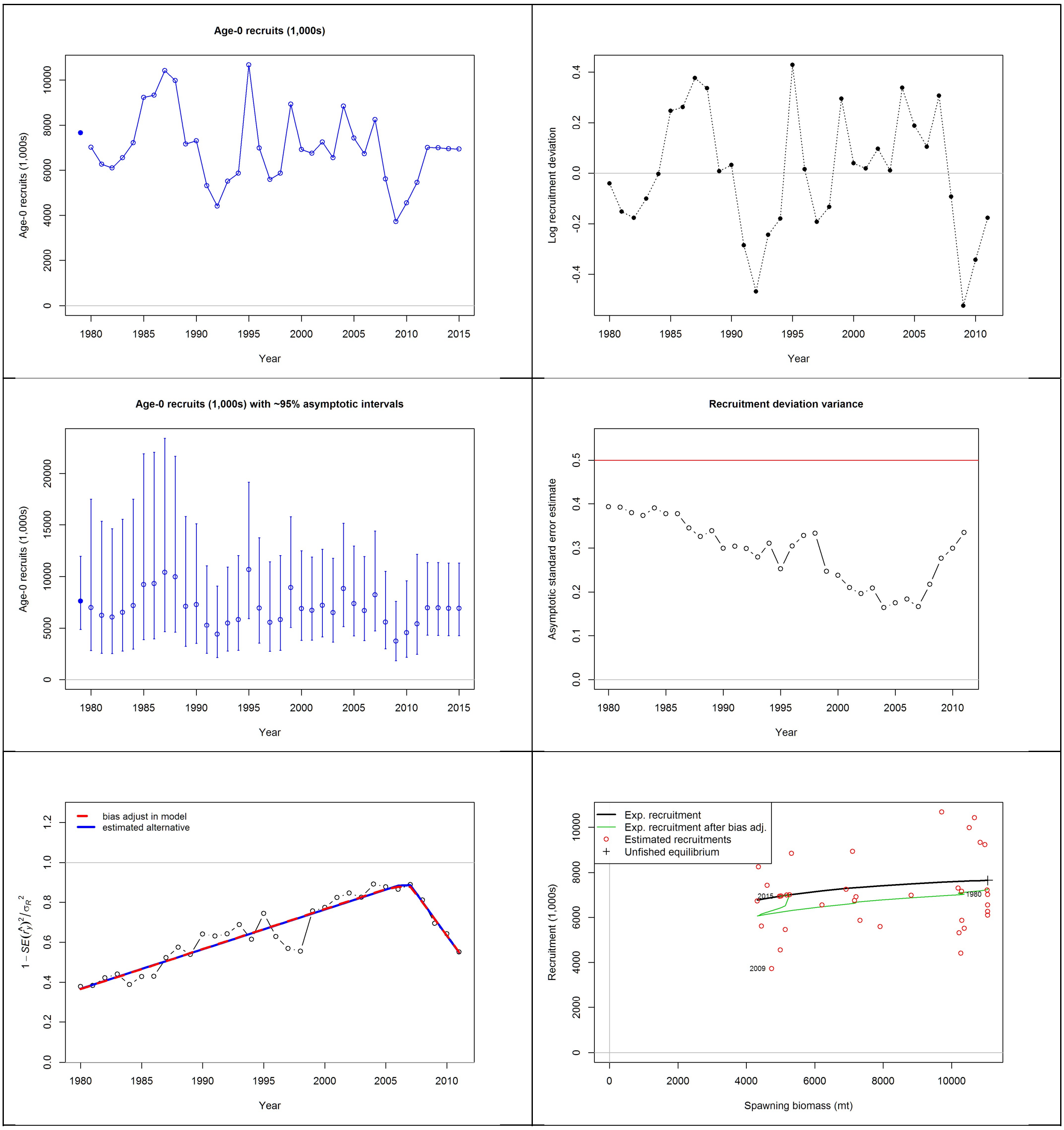


Figure 16.19. Estimation of recruitment and recruitment deviates for the base-case assessment with time trajectories given in both nominal and log-space. The final nine deviates in the middle left are not estimated but are estimated by the implied Beverton-Holt stock recruitment curve. The asymptotic 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 appears to be related to the advent of more ageing data from the FIS and additional length-composition data streams.

The inclusion of recruitment estimates for more recent years also, not surprisingly, indicates some relatively low and some relatively high values. There are now no prolonged periods of high or low recruitment apparent in the time series (Figure 16.20).

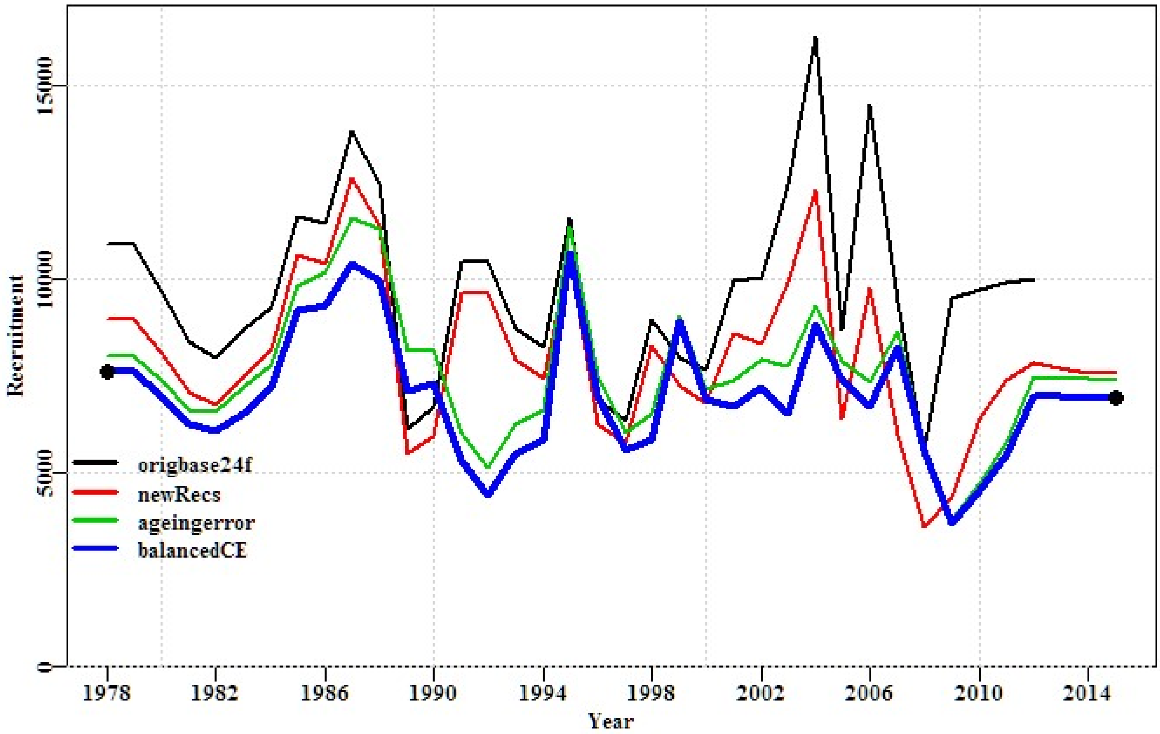


Figure 16.20. The sequence of expected recruitment levels through time for five different scenarios (more becomes uninterpretable). The difference between the 'newRecs' series and he base-case 'balancedCE' illustrates the differences that the rebalancing can bring about.

The recruitment levels and recruitment deviates through the period of the fishery have not varied to any extreme extent (Figure 16.20). There have been no extensive periods of below or above average recruitment levels predicted throughout the fishery. The effect of increasing and decreasing this variation is examined in the sensitivities (Table 16.16).

16.4.4.1 Recommended Biological Catches

The 2017/2018 recommended biological catch (RBC) under the 20:35:43 harvest control rule is 1155 t and the long term yield (assuming average recruitment in the future) is 1093 t (Table 16.14). Averaging the RBC over the three year period 2017/2018 – 2019/2020, the average RBC is 1128 t and over the five year period 2017/2018 – 2021/2022, the average RBC is 1115t (Table 16.14).

The forecast estimates of future RBCs are dependent upon first predicting the catch in the incomplete season 2016/2017 so that the predicted catch that is equivalent to $F_{43\%}$ can be generated for the 2017/2018 onwards. The basecase projection is based upon the assumption that the catch in 2016/2107 will be the same as happened in 2015/2016. In the December RAG this was questioned and alternative possible catches were suggested so that projections were made assuming 600t and 1000t (Table 16.15). As expected these led to small reductions in the 1, 3, and 5 year RBCs although, again as expected, the Long Term Yield remained at 1093 t.

Table 16.14. 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 2017/2018 fishing year and the long-term RBC that should maintain the stock at the target of 43%B_0. See Table 16.18 for the projection outcomes for all years.

Year	Total Exploitable Biomass	Spawning Biomass	Catch	Depletion
Unfished	21058	11046	0	1
1979	21058	11046	0	1
1980	21057	11046	0	1
1981	21050	11046	0	1
1982	21018	11046	0	1
2014	10260	4992	567	0.452
2015	10379	4951	523	0.448
2016	10611	4993	523	0.450
2017	10910	5123	1155	0.464
2018	10668	4966	1125	0.450
2019	10514	4859	1106	0.440
2020	10427	4790	1096	0.434
2021	10384	4752	1092	0.430
2051	10398	4745	1093	0.430
2052	10398	4745	1093	0.430
2053	10399	4746	1093	0.430
2054	10399	4746	1093	0.430
2055	10400	4746	1093	0.430

Table 16.15. The forecast one year, three year, and five year RBCs are listed for the 20:35:43 harvest control rule and the original 20:35:48 harvest control rule to illustrate the difference between the proxy for MEY being 48%B_0 relative to the estimate of 43%B_0. These are based on a predicted catch in 2016/2017 assumed equal to that in 2015/2016. To test the sensitivity of the outcome to this assumption alternative assumed catches of 600t and 1000t in 2016/2017.

Forecast	20:43	20:48	16/17 = 600t	16/17=1000t
2017/2018 RBC	1155	939	1146	1102
17/18 – 19/20 RBC	1128	938	1121	1085
17/18 – 19/20 RBC	1115	945	1109	1078
Long Term Yield	1093	1029	1093	1093

16.4.5 *Sensitivity Tests*

The sensitivity tests demonstrate that the assessment outcomes are very sensitive to the assumed value for *M*, the natural mortality (Figure 16.21; Table 16.16). 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 16.21; Table 16.16). This is also a reflection of the limited rebalancing of variances conducted once large amounts of new data began to be added to the model. Without such rebalancing the advent of the new age data, for example, appeared to drop the spawning stock biomass down to just above 20%B_0, which was merely an artefact of enormous weight being given to the ageing data through the addition of hundred of new observations.

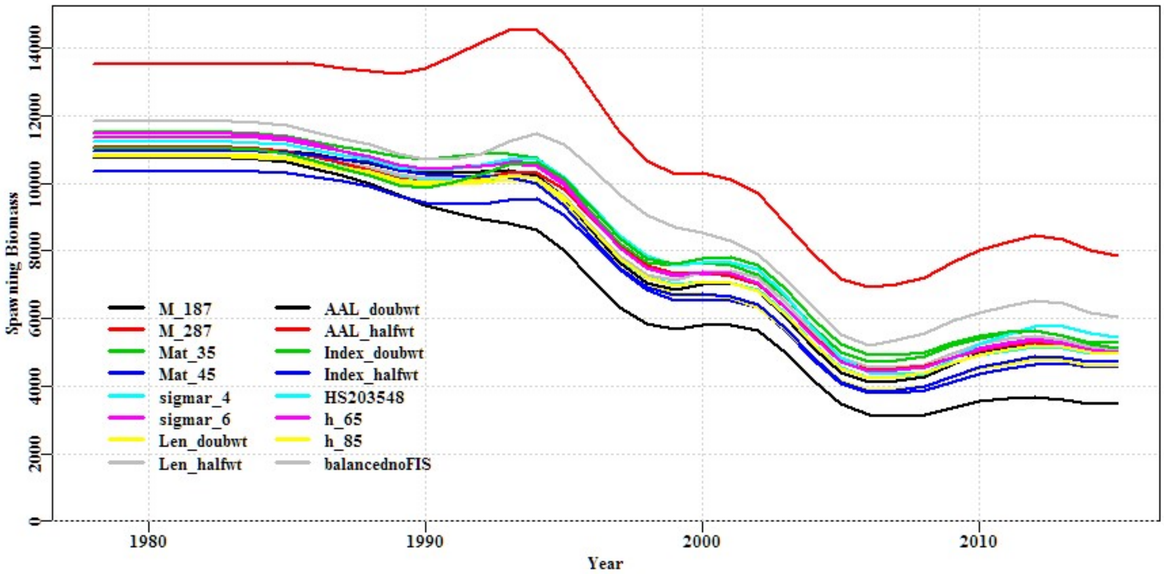


Figure 16.21. The effect on the predicted spawning biomass trajectory of the sensitivity tests on different assumptions and data weightings. The sensitivity to different assumed values of natural mortality is apparent.

In the sensitivities altering the weights on the different data streams had some effects on the model outcomes especially the halving and doubling the weights on the age composition data, (Table 16.16). However, by changing the weight given to each data stream it is no longer valid to compare the likelihoods from such sensitivity tests. The overall fit of the model improved with greater weight on the length and age 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 even though they have only a small effect on the biomass related model outcomes (Table 16.16).

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.

The effect of changing the SigmaR value alters how variable the recruitment deviates can be from year to year. However, once again the effect on the stock depletion status is minor varying the estimate from 44.1% – 45.9%.

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. More importantly, the higher the M the greater the degree of depletion so increasing M by 0.05 led to the depletion changing from 45% down to 32% while decreasing it by 0.05 changed depletion from 45% to 58%. The influence of the natural mortality estimate is clear.

When all data from the FIS was removed this alters the model structure, which means it is no longer directly comparable with the full basecase. Nevertheless, the effect is to alter depletion from 45% to 51%, so the FIS is clearly generating information about the stock, particularly about the smaller fish.

All other sensitivities had only small effects on the outcome of the assessment with the final depletion ranging only 1 – 2 % from the basecase depletion. This may be a reflection of the strong contrast in the fishery where it was fished hard in the mid-1990s and the early 2000s with far reduced catches in between. Such fishing behaviour may provide difficult marketing conditions but it does provide information on how a stock responds to widely different fishing mortality levels and provides insight into its potential productivity.

16.4.5.1 Likelihood Profile on Natural Mortality

By fixing the value of natural mortality over an array of different values and re-fitting the assessment model so that all other parameters (except natural mortality) are re-estimated, it is possible to both determine the relative precision of the natural mortality estimate as well as the consequences for the stock and its status if different natural mortality values were used (Table 16.17 and Figure 16.22).

The profile likelihood enables approximate 95% confidence intervals to be generated (Venzon and Moolgavkar (1988). By searching for the natural mortality values that match the minimum obtained from the balancedCE scenario + 1.92 this provides approximate 95% intervals on natural mortality: 0.1628 – 0.1914 – 0.2285. This implies a range of depletion from 38 – 54% (Table 16.17; Figure 16.22), which is rather a wide range. Clearly, like most species, the natural mortality is a highly influential factor in the biology of Deepwater Flathead.

Table 16.16. 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_{2016}	SSB_{2016}/SSB_0	M	TotalLL	Index	AgeComp	LenComp	Recruit
Base-Case	**base case 20:35:43**	**11046**	**4974**	**0.450**	**0.191**	**336.92**	**-27.52**	**290.23**	**84.68**	**-10.46**
MHigh	$M =$ 0.241	10757	3461	0.322	0.141	-7.78	-4.41	-2.95	0.87	-1.29
MLow	$M =$ 0.141	13509	7854	0.581	0.241	-3.58	1.76	-3.19	-1.80	-0.35
MatHigh	50% maturity at 45cm	11512	5282	0.459	0.191	0.00	-0.02	0.00	0.01	0.00
MatLow	50% maturity at 35cm	10332	4537	0.439	0.192	0.01	0.03	0.00	-0.02	0.01
SigRHigh	$\sigma_R = 0.6$	10796	4954	0.459	0.189	2.94	-0.23	-0.73	-0.04	3.95
SigRLow	$\sigma_R = 0.4$	11459	5050	0.441	0.194	-2.70	0.08	0.38	-0.03	-3.14
LFwtx2	wt x 2 length comp	*10773*	*4617*	*0.429*	*0.186*	*-82.63*	*-2.11*	*-2.94*	-77.18	-0.40
LFwtx0.5	wt x 0.5 length comp	*11040*	*5060*	*0.458*	*0.196*	*43.34*	*1.44*	*1.99*	40.08	-0.16
agewtx2	wt x 2 age comp	*10954*	*4982*	*0.455*	*0.189*	*-288.08*	*-1.13*	*-282.64*	-3.27	-1.05
agewtx0.5	wt x 0.5 age comp	*11074*	*4990*	*0.451*	*0.195*	*146.07*	*0.85*	*142.88*	1.80	0.54
cpuewtx2	wt x 2 CPUE	*11033*	*5113*	*0.463*	*0.202*	*29.55*	*34.40*	*-1.52*	-2.30	-1.04
cpuewtx0.5	wt x 0.5 CPUE	*10953*	*4747*	*0.433*	*0.184*	*-13.13*	*-15.29*	*0.56*	1.31	0.29
hHigh	Fix steepness $h = 0.85$	11364	5009	0.441	0.194	-0.11	0.11	-0.02	-0.16	-0.04
hLow	Fix steepness $h = 0.65$	10839	4962	0.458	0.189	0.05	-0.08	0.01	0.11	0.01
noSurvey	No Survey data	*11825*	*6042*	*0.511*	*0.202*	*202.53*	*-4.48*	*188.74*	22.81	-4.54

Table 16.17. The outcome from the profile likelihood conducted on natural mortality including the influence on the different likelihood components and on the Unfished spawning biomass (B_0), the current biomass, and the depletion.

M	TotalLike	TotalCE	TotalLF	TotalAge	CPUE	FISCE	TrawlLF	FISLF	IndustLF	PortLF	TrawlAge	FISAge	B0	Bcurr	Depletion
0.14	354.184	-22.989	83.814	293.359	-15.983	-7.006	24.009	20.376	10.267	29.161	2527.530	406.065	10765.500	3438.060	0.319
0.145	352.747	-23.616	83.809	292.554	-16.689	-6.927	24.316	20.205	10.211	29.077	2518.790	406.752	10727.100	3555.420	0.331
0.15	351.525	-24.195	83.831	291.889	-17.342	-6.853	24.616	20.048	10.159	29.008	2511.470	407.417	10701.400	3677.930	0.344
0.155	350.497	-24.730	83.877	291.349	-17.946	-6.784	24.909	19.903	10.112	28.953	2505.430	408.061	10689.000	3806.170	0.356
0.16	349.642	-25.223	83.943	290.922	-18.504	-6.719	25.196	19.770	10.068	28.909	2500.540	408.684	10690.400	3940.730	0.369
0.165	348.948	-25.677	84.027	290.598	-19.019	-6.658	25.475	19.648	10.028	28.877	2496.690	409.289	10706.200	4082.280	0.381
0.17	348.396	-26.095	84.125	290.366	-19.494	-6.601	25.747	19.535	9.990	28.854	2493.790	409.874	10737.100	4231.530	0.394
0.175	347.976	-26.479	84.237	290.218	-19.931	-6.548	26.012	19.430	9.955	28.839	2491.740	410.442	10783.800	4389.250	0.407
0.18	347.676	-26.831	84.360	290.147	-20.333	-6.499	26.271	19.334	9.922	28.833	2490.480	410.993	10847.200	4556.320	0.420
0.185	347.485	-27.154	84.494	290.145	-20.702	-6.453	26.524	19.244	9.892	28.834	2489.920	411.530	10928.100	4733.670	0.433
0.19	347.393	-27.450	84.637	290.206	-21.039	-6.411	26.771	19.161	9.863	28.841	2490.010	412.051	11027.800	4922.360	0.446
0.1913	347.384	-27.523	84.676	290.232	-21.123	-6.400	26.835	19.141	9.856	28.845	2490.130	412.187	11057.300	4974.120	0.450
0.195	347.393	-27.720	84.788	290.325	-21.348	-6.372	27.012	19.084	9.836	28.855	2490.690	412.560	11147.300	5123.540	0.460
0.2	347.478	-27.966	84.947	290.497	-21.630	-6.337	27.249	19.013	9.811	28.875	2491.910	413.057	11288.100	5338.530	0.473
0.205	347.640	-28.190	85.113	290.717	-21.886	-6.305	27.480	18.946	9.788	28.900	2493.620	413.544	11451.700	5568.770	0.486
0.21	347.872	-28.394	85.285	290.981	-22.118	-6.276	27.707	18.883	9.765	28.930	2495.790	414.021	11640.100	5815.890	0.500
0.215	348.172	-28.579	85.464	291.287	-22.328	-6.250	27.931	18.824	9.744	28.965	2498.380	414.490	11855.100	6081.710	0.513
0.22	348.531	-28.746	85.648	291.629	-22.518	-6.228	28.150	18.768	9.724	29.005	2501.340	414.953	12099.300	6368.250	0.526
0.225	348.948	-28.897	85.838	292.007	-22.688	-6.209	28.367	18.715	9.705	29.050	2504.660	415.412	12375.300	6677.800	0.540
0.23	349.416	-29.033	86.033	292.416	-22.840	-6.193	28.581	18.665	9.687	29.100	2508.300	415.867	12686.000	7012.880	0.553
0.235	349.934	-29.155	86.233	292.856	-22.975	-6.180	28.792	18.617	9.670	29.154	2512.240	416.322	13034.900	7376.290	0.566
0.24	350.497	-29.264	86.438	293.323	-23.095	-6.170	29.001	18.570	9.654	29.214	2516.450	416.777	13425.800	7771.120	0.579
0.245	351.103	-29.362	86.649	293.816	-23.200	-6.163	29.208	18.525	9.638	29.278	2520.920	417.236	13862.700	8200.710	0.592
0.25	351.749	-29.450	86.865	294.334	-23.291	-6.159	29.414	18.481	9.623	29.348	2525.640	417.702	14350.200	8668.670	0.604
0.255	352.433	-29.529	87.087	294.875	-23.371	-6.158	29.619	18.436	9.608	29.423	2530.570	418.177	14893.000	9178.720	0.616
0.26	353.154	-29.599	87.314	295.439	-23.440	-6.159	29.824	18.392	9.594	29.504	2535.720	418.667	15496.100	9734.640	0.628

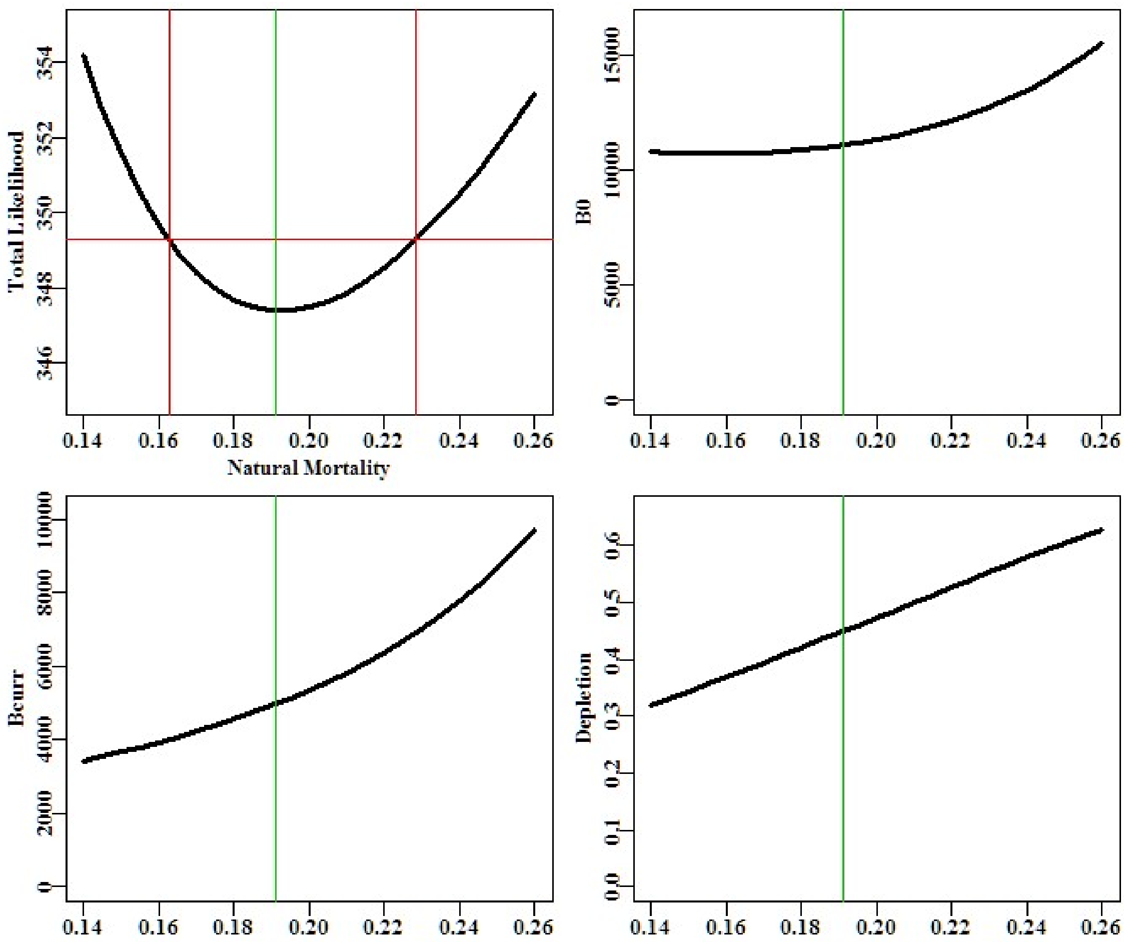


Figure 16.22. The likelihood profile for natural mortality (top right) with its implications for the unfished spawning biomass (B_0), the Current biomass and the state of depletion. The green line depicts the optimum estimate of natural mortality in all cases. In the likelihood profile the red lines bound the approximate likelihood profile 95% confidence bounds.

Table 16.18. Tabulated deterministic output from the projections. The filled dots in Figure 16.18 are the year and Depletion column values (as proportions not percentages).

Year	Total Biomass	Spawning Biomass	Recruitment	Depletion	TAC
2016	11164	5318	6612	0.475	1171
2017	10783	5019	6549	0.448	1120
2018	10572	4858	6513	0.434	1093
2019	10475	4780	6495	0.427	1082
2020	10445	4754	6488	0.424	1079
2021	10448	4755	6489	0.424	1081
2022	10462	4766	6491	0.425	1084
2023	10479	4777	6494	0.426	1086
2024	10494	4785	6496	0.427	1088
2025	10506	4792	6497	0.428	1090
2026	10516	4796	6498	0.428	1091
2027	10524	4800	6499	0.428	1092
2028	10530	4803	6500	0.429	1092
2029	10535	4805	6501	0.429	1093
2030	10540	4807	6501	0.429	1093
2031	10543	4809	6502	0.429	1094
2032	10546	4810	6502	0.429	1094
2033	10549	4812	6502	0.429	1095
2034	10551	4813	6502	0.429	1095
2035	10553	4814	6503	0.430	1095
2036	10554	4814	6503	0.430	1095
2037	10555	4815	6503	0.430	1095
2038	10556	4816	6503	0.430	1095
2039	10557	4816	6503	0.430	1095
2040	10558	4816	6503	0.430	1096
2041	10559	4817	6503	0.430	1096
2042	10559	4817	6503	0.430	1096
2043	10560	4817	6503	0.430	1096
2044	10560	4818	6504	0.430	1096
2045	10560	4818	6504	0.430	1096
2046	10561	4818	6504	0.430	1096
2047	10561	4818	6504	0.430	1096
2048	10561	4818	6504	0.430	1096
2049	10561	4818	6504	0.430	1096
2050	10562	4818	6504	0.430	1096
2051	10562	4818	6504	0.430	1096
2052	10562	4818	6504	0.430	1096
2053	10562	4818	6504	0.430	1096
2054	10562	4818	6504	0.430	1096
2055	10562	4818	6504	0.430	1096

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16.6 Appendix

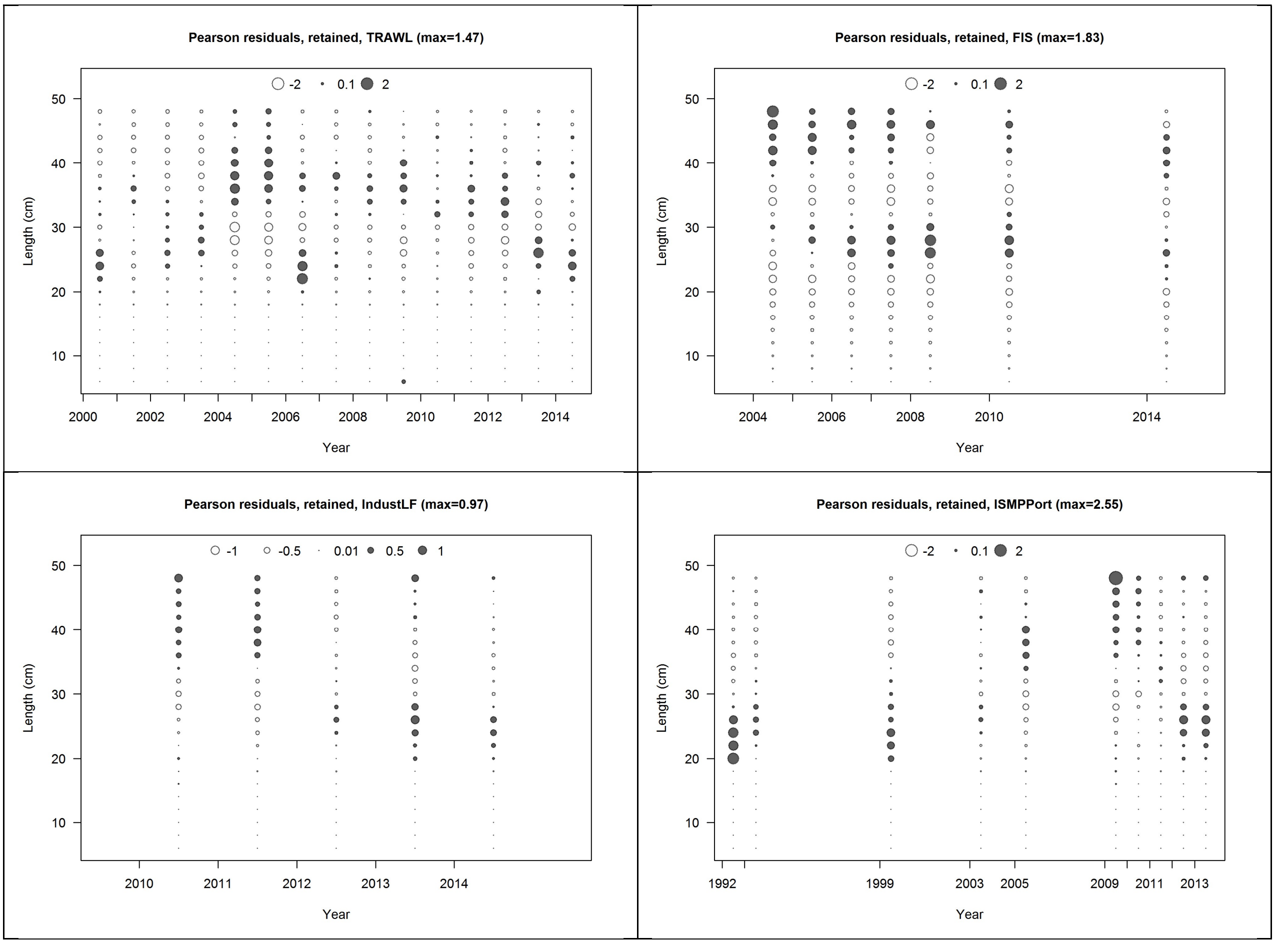

Figure 16.23. Residuals from the annual length composition data (retained) for Deepwater Flathead displayed by year and fleet (TRAWL – ISMP_onboard).

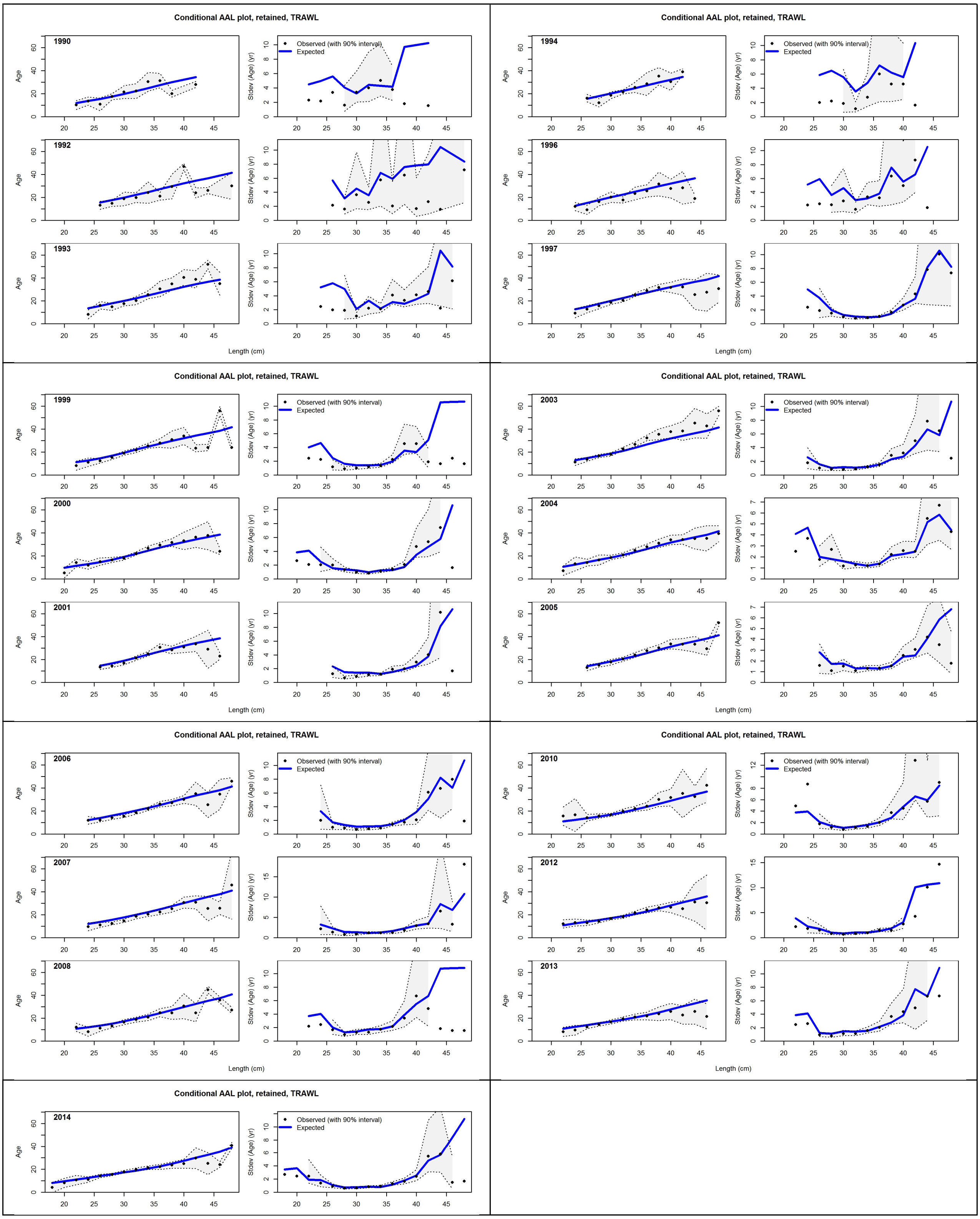

Figure 16.24. Conditional age-at-length plots illustrating the ages expected each year from the sampled length composition data and the age-length key for the year.