Deepwater Flathead (*Neoplatycephalus conatus*) stock assessment based on data up to 2022/23

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Executive summary

This document presents a suggested base case for an updated quantitative Tier 1 Deepwater Flathead (*Neoplatycephalus conatus*) assessment for presentation at the first GABRAG meeting in October 2023. The last full assessment was presented in Tuck et al. (2019). The preliminary base case has been updated by the inclusion of data up to the end of 2022/23, which entails an additional four years of catch, trawl CPUE, length and age data and ageing error updates since the 2019 assessment, and incorporation of survey results from the last GAB Fishery Independent Survey (GABFIS). As agreed by GABRAG in October 2023, the base case model includes a separate fleet for Danish seine. The process used to develop a preliminary base case for Deepwater Flathead through the sequential updating of recent data and updating the stock assessment package Stock Synthesis (SS-V3.30.21.00) was presented in October 2023. This document provides further detail of the agreed base case, with RBC values and sensitivities to the base case model structure. As seen in October 2023, the base case provides reasonably good fits to the catch rate data, length data and conditional age-at-length data, however, the fit to the most recent GABFIS points is poor.

The 2023 assessment estimates that the projected 2024/25 spawning stock biomass will be 44% of virgin stock biomass (projected assuming 2022/23 catches in 2023/24), compared to 45% at the start of 2020/21 from the 2019 assessment (Tuck et al., 2019).

The 2024/25 Recommended Biological Catch (RBC) under the 20:35:43 harvest control rule is 1,220 t. The average RBC over the four-year period 2024/25 - 2027/28 is 1,209 t. The long-term RBC is 1,199 t.

1 Introduction

1.1 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. Deepwater Flathead are endemic to Australia and inhabit waters from northwest Tasmania, west to north of Geraldton in Western Australia (WA) in depths from 70m to more than 510m (Kailola et al., 1993; Gomon et al., 2008; www.fishbase.org).

1.2 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 spawning 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 model for Deepwater Flathead was 20,418t. The absolute biomass estimate from the survey at that time was consistent with other fishery data for Deepwater Flathead. Survey estimates are now treated as indices of relative abundance separate from those 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 Stock Synthesis, most importantly the estimation of recruitment residuals independently and allowing the estimation of recruitment residuals 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, SSB_0, was estimated as 10,366t and current depletion at 62% of SSB_0. 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 near the 20% B_0 limit. Previous assessments had all indicated a stock in fish-down, but always above the target biomass.

The 2012 Deepwater Flathead assessment (Klaer 2013a, b) estimated 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. An assessment was conducted in 2013 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 RBC under the 20:35:43 harvest control rule was 1,146t and the long-term yield (assuming average recruitment in the future) was 1,105 t.

The Deepwater Flathead assessment conducted in 2016 used data to the end of 2015/16 (Haddon, 2016). 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, and the industry collected length composition data were also included. The base-case assessment estimated that the female spawning stock biomass at the start of 2016/2017 was 45% of unexploited female spawning stock biomass (SSB_0). The 2017/2018 recommended biological catch (RBC) under the agreed 20:35:43 harvest control rule was 1,155 t and the long-term yield (assuming average recruitment in the future) was 1,093 t. The unexploited female spawning biomass in 2016/2017 was estimated as 11,046 t.

The last assessment of Deepwater Flathead was conducted in 2019 (Tuck et al., 2019a, b). The base case provided reasonably good fits to the catch rate data, length data and conditional age-at-length data, however, the fit to the two most recent GABFIS points was poor. The assessment estimated that the 2020/21 spawning stock biomass will be 45% of virgin stock biomass and the 2020/21 Recommended Biological Catch under the 20:35:43 harvest control rule was 1,253 t, and the long-term yield (assuming average recruitment in the future) was 1,218 t. The unexploited female spawning biomass in 2020/21 was estimated as 9,008 t.

Table 1. A summary of stock assessment outcomes for Deepwater Flathead. B_0 is the unfished female spawning biomass. The yield is the RBC for the following year with the long term estimated sustainable yield (LTY) 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. ^ Total biomass

Year	Authors	B_0 (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)	8,921	39	979 (1,051)
2013	Klaer (2013b)	9,320	45	1,146 (1,105)
2016	Haddon (2016)	11,046	45	1,155 (1,093)
2019	Tuck et al. (2019b)	9,008	45	1,253 (1,218)
2023	Tuck et al. (2023)	9,918	44	1,220 (1,199)

2 Methods

2.1 Modifications to the previous assessment

An initial base case quantitative Tier 1 Deepwater Flathead assessment was developed and presented to the GABRAB on the 17th October 2023 (Tuck and Bessell-Browne, 2023); this was used to describe the changes from the previous assessment by the sequential addition of the new data now available (known as a bridging analysis) along with other structural changes. The last full assessment was presented in Tuck et al. (2019b).

The preliminary base case was updated by the inclusion of data up to the end of 2022/23, which entails an additional four years of catch, trawl CPUE, length and age data and ageing error updates since the 2019 assessment, and incorporation of the last survey result from the Fishery Independent Survey (GABFIS) and using the stock assessment package Stock Synthesis (SS-V3.30.21.00). It was agreed by members of GABRAG (October 2023) that the base case assessment model should include Danish seine as a separate fleet for RBC recommendations. This document provides further details of the base case model, RBC recommendations and sensitivities.

2.2 Model structure

The 2023 preliminary base case assessment of Deepwater Flathead uses an age- and size-structured model implemented in the generalised stock assessment software package, Stock Synthesis (SS) (Version SS-V3.30.21.00, Methot et al. (2022)). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterised in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters are estimated by fitting to data on catches, trawl CPUE, survey estimates of biomass, retained length-frequencies, conditional age-at-length data and ageing error. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS operating manual (Methot, 2015) and technical description (Methot and Wetzel, 2013) and are not reproduced here.

A two-sex stock assessment for Deepwater Flathead was implemented in Stock Synthesis. 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. The selectivity pattern for both the trawl and Danish seine fleets were modelled as logistic functions and not changing through time. The two parameters of the logistic selectivity function for each fleet were estimated within the assessment. Length based logistic selectivity is estimated separately for the GABFIS fleet.

Male and female Deepwater Flathead are assumed to have the same biological parameters except for their growth and the length-weight relationship (Table 2). The four parameters relating to the von Bertalanffy growth equation for females 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 previous assessment assumed a fixed value for the length at maximum age for females. This assumption has now been removed and the parameter is estimated within the model. Likewise, the CV on growth is now estimated for both sexes, except for the CV on old males (assumed equal to the female value; estimating this parameter led to the model failing to converge).

The rate of natural mortality, *M*, was assumed to be constant with age, and also time invariant. *M* is estimated in the base-case model. Maturity is modelled as a logistic function, with 50% maturity fixed at 40 cm (Brown and Sivakumaran, 2007). 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 2016/2017. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was set equal to 0.7. Age 29 is treated as a plus group into which all animals predicted to survive to ages greater than 29 are accumulated.

The October 2023 GABRAG agreed that the new base case model structure should have a Danish seine fleet separate from the trawl fleet. Previous base case models included the Danish seine catch with the trawl catch. The 2023 base case includes a separate selectivity function for Danish seine, with associated catches, lengths and ages from onboard and port sampling.

2.3 Available data

An array of different data sources are available for the Deepwater Flathead assessment including catch, standardized commercial trawl CPUE, an index of relative abundance from the GAB Fishery Independent Survey (FIS), age-at-length data from the Integrated Scientific Monitoring Program (ISMP) and from the FIS, and length composition data for the trawl and Danish seine fleets from: the ISMP (keeping port sampling separate from the on-board sampling), the FIS, and from on-board crew sampling (Figure 1).

Table 2 Summary of selected parameters from the 2023 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 samples collected during the 2001 FRDC project. Years represent the first year of each financial year (i.e. 2015 = 2015/2016).

Description	Parameter		
Years	y	1988/89 – 2022/23	
Recruitment Deviates	*r*	estimated 1980 - 2016	
Fleets		Trawl and DS	
Abundance indices		GABFIS, Trawl CPUE	
Discards		negligible, not fitted	
Age classes	*a*	0 – 29 years	
Sex ratio	p_s	0.5 (1:1)	
Natural mortality	*M*	estimated (male and female equivalent)	
Steepness	*h*	0.75	
Recruitment variation	σ_r	0.7	
Female maturity[1]		40 cm (TL)	
		Female	Male
Growth	L_{max}	fitted	fitted
	K	fitted	fitted
	L_{min}	fitted	fitted
	CV young	fitted	fitted
	CV old	fitted	fixed
Length-weight (based	f_1	0.002 cm (TL)/gm	0.002
on standard length)[2]	f_2	3.332	3.339

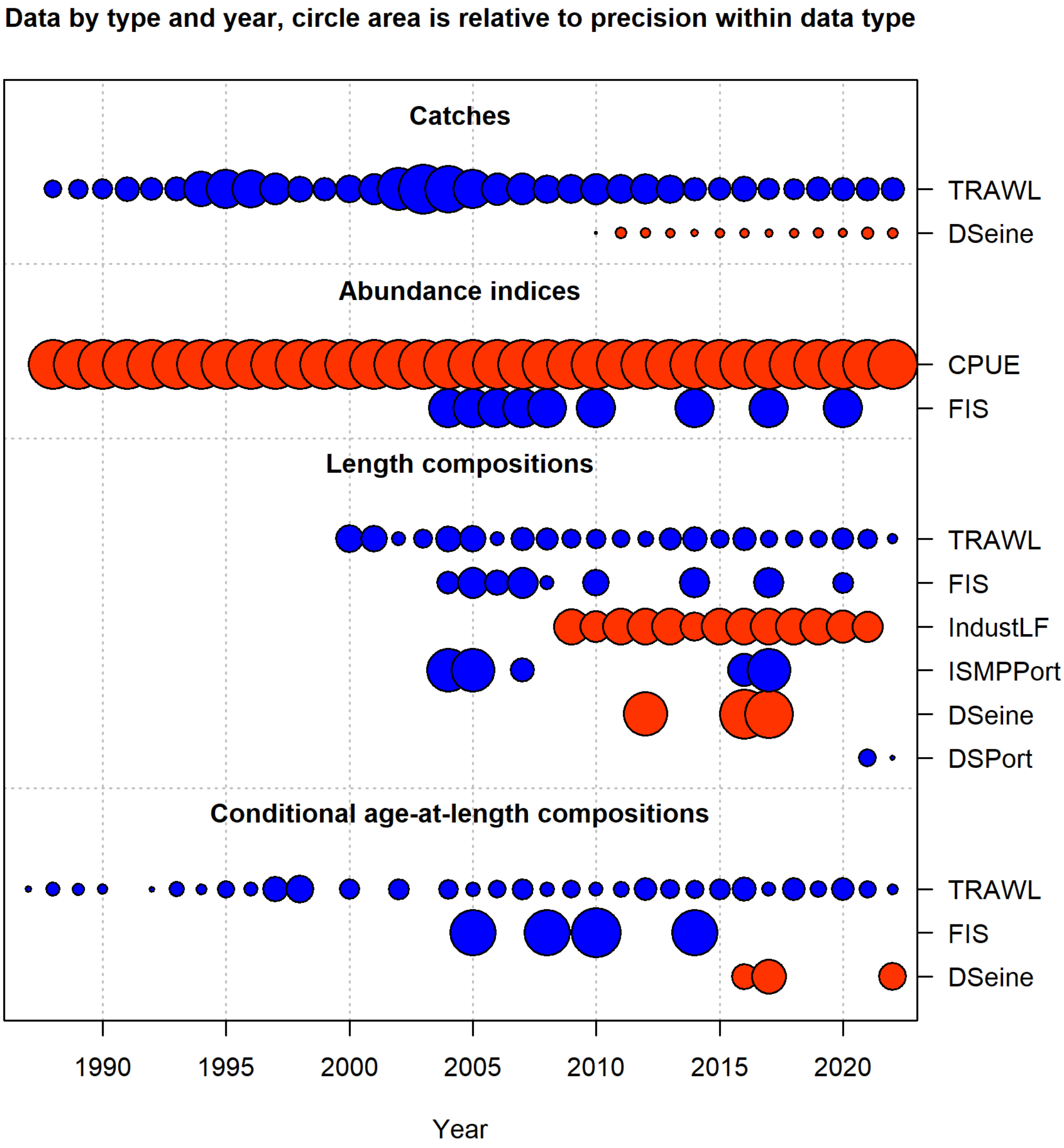


Figure 1. Summary of data sources for the 2023 base case Deepwater Flathead stock assessment.

2.3.1 Landings and catch rates

The catch data for the 2023 assessment for Deepwater Flathead comes from the trawl and Danish seine fleets operating in the GAB. The catch history for Deepwater Flathead is available for the years from 1988/1989 to 2022/23 (Table 3). Landed catches were derived from GAB logbook records for the years to 2005 and catch disposal records (CDRs) 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. The 2022/23 catch value was assumed for the 2023/24 catch for projections and calculation of the 2024/25 RBC.

Catch rates from the trawl fishery were updated according to Sporcic (2023). The updated catch and catch rate data are in Table 3.

Table 3. Financial year estimates of catch (t) and the standardized trawl CPUE for Deepwater Flathead in the GAB from 1988/1989 – 2022/2023. Catch is taken from logbook estimates until 2005/06 (Klaer, 2013; Haddon, 2016). Subsequently CDR catches are used. Discards are assumed to be negligible. Standardized CPUE is from Sporcic (2023). † Note Deepwater Flathead catches for 2023/24 are assumed to be the same as those from 2022/23.

Season	TW	DS	Total	CPUE
88/89	312		312	1.0354
89/90	395		395	1.0428
90/91	420		420	1.0228
91/92	608		608	0.9856
92/93	508		508	1.26
93/94	585		585	1.7066
94/95	1255		1255	2.0984
95/96	1552		1552	2.013
96/97	1459		1459	1.3392
97/98	1010		1010	0.9295
98/99	681		681	0.7141
99/00	545		545	0.849
00/01	777		777	0.9252
01/02	964		964	1.1124
02/03	1866		1866	1.5347
03/04	2482		2482	1.5293
04/05	2264		2264	1.2076
05/06	1546		1546	0.7694
06/07	1030		1030	0.7114
07/08	1025		1025	0.7819
08/09	800		800	0.9312
09/10	851		851	0.8238
10/11	963	5	968	1.0445
11/12	849	125	973	0.8324
12/13	931	97	1028	0.8306
13/14	800	87	887	0.7264
14/15	537	58	595	0.6729
15/16	524	92	616	0.7501
16/17	643	89	732	0.7942
17/18	470	68	538	0.5974
18/19	431	86	518	0.6124
19/20	594	99	693	0.7452
20/21	559	78	636	0.8289
21/22	536	143	679	0.8501
22/23	565	111	676	0.9248
23/24†	565	111	676	-

2.3.2 Fishery independent survey abundance estimates

There are nine estimates of relative abundance from the trawl Fishery Independent Survey (Knuckey et al., 2021). The CV estimates for the abundance estimates are initially set at 0.10, but in the process of balancing the output variability with that input, these values are re-estimated (Table 4).

Table 4. FIS relative abundance estimates for Deepwater Flathead, with each survey estimate's coefficient of variation (taken from Knuckey *et al*., 2021).

Year	2004/05	2005/06	2006/07	2007/08	2008/09	2010/11	2014/15	2017/18	2020/21
Estimate	12,152	8,415	8,540	7,725	9,942	9,227	5,065	3,396	5,225
CV (original)	0.05	0.06	0.05	0.06	0.05	0.05	0.09	0.06	0.08

2.3.3 Age data

An estimate of the standard deviation of age reading error from data supplied by Fish Ageing Services is in Table 5. It is assumed Reader (2) relates to years 2000, 2002-2007. All other years are associated with Reader (1).

Age data exist from the ISMP sampling program for trawl and Danish seine, and the GABFIS. Numbers of age samples by fleet and year are provided in Table 6.

Table 5. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes of Deepwater Flathead for two readers (1) and (2).

Age	StDev (1)	StDev (2)	Age	StDev (1).	StDev (2)	Age	StDev (1).	StDev (2)
0	0.229109	0.237189	10	0.484074	0.522309	20	0.71114	0.666282
1	0.229109	0.237189	11	0.509238	0.542689	21	0.731067	0.675116
2	0.260154	0.280433	12	0.533822	0.561434	22	0.750535	0.683242
3	0.290482	0.32021	13	0.557839	0.578676	23	0.769553	0.690716
4	0.320111	0.356797	14	0.581301	0.594536	24	0.788133	0.697591
5	0.349057	0.390449	15	0.604223	0.609124	25	0.806284	0.703914
6	0.377335	0.421403	16	0.626616	0.622542	26	0.824016	0.709731
7	0.404961	0.449875	17	0.648492	0.634884	27	0.84134	0.715081
8	0.43195	0.476064	18	0.669864	0.646236	28	0.858264	0.720002
9	0.458316	0.500152	19	0.690743	0.656678	29	0.874797	0.724528

Table 6. Number of age-length otolith samples included in the base case assessment by fleet.

Year	Trawl	DS	FIS
1987	61		
1988	290		
1989	214		
1990	146		
1991			
1992	50		
1993	358		
1994	178		
1995	430		
1996	287		
1997	972		
1998	1163		
1999			
2000	600		
2001			
2002	642		
2003			
2004	565		
2005	326		229
2006	484		
2007	650		
2008	329		225
2009	465		
2010	290		262
2011	367		
2012	787		
2013	528		
2014	519		225
2015	666		
2016	879	250	
2017	293	439	
2018	775		
2019	407		
2020	789		
2021	423		
2022	774	280	

2.3.4 Length composition data

Length data exist from ISMP sampling (onboard and port) of the trawl and Danish seine fleets, the GABFIS and industry sampling programs (Table 7-8). As is standard practice, the ISMP onboard and port length samples are separately fit in the model. A logistic selectivity curve for each of trawl and Danish seine is estimated as a function of length using length data from the ISMP and the industry sampling program (for trawl). The GABFIS has a separate selectivity using the FIS lengths. The length compositions for each source are illustrated in the Appendix.

Standard length filtering procedure requires that there are at least 100 measured fish for length-composition data to be included in the assessment. For onboard samples, numbers of shots were used as the sampling unit (i.e. the stage-1 weights; Francis (2011)), with a cap of 200. For port samples, numbers of trips were used as the sampling unit, with a cap of 100. For industry samples, numbers of days of sampling were used as the sampling unit, with a cap of 200. The number of fish measured is not used as the sample size because the appropriate sample size for length-composition data is probably more closely related to the number of shots (onboard), trips (port) or days (industry) sampled, rather than the number of fish measured.

Table 7. Number of onboard retained lengths and number of shots, days or trips for length frequencies included in the base case assessment by fleet for the trawl fleet.

Year	Trawl Onboard		Industry Sampling		Trawl Port	
	Shots	Fish	Days	Fish	Trips	Fish
2000	66	6885				
2001	58	6402				
2002	17	2273				
2003	31	3514				
2004	56	3064			27	3009
2005	58	3562			27	2823
2006	17	980				
2007	45	1575			8	364
2008	41	1480				
2009	30	1878	195	16096		
2010	33	932	148	18749		
2011	27	1375	223	20260		
2012	21	1396	212	13205		
2013	42	1728	227	11065		
2014	51	2615	126	5935		
2015	29	1210	224	17319		
2016	47	2279	286	22318	15	1667
2017	24	1171	285	22185	27	2378
2018	25	1016	335	26467		
2019	24	416	340	29185		
2020	38	1751	162	9013		
2021	32	1105	142	8483		
2022	9	845				

Table 8. Number of onboard retained lengths and number of shots or trips for length frequencies included in the base case assessment by fleet for the GABFIS and Danish seine fleet.

Year	FIS		DS Onboard		DS Port	
	Shots	Fish	Shots	Fish	Trips	Fish
2000						
2001						
2002						
2003						
2004	29	1135				
2005	54	1790				
2006	35	937				
2007	54	2417				
2008	11	1382				
2009						
2010	40	1002				
2011						
2012			22	664		
2013						
2014	51	1337				
2015						
2016			28	1488		
2017	52	1056	27	361		
2018						
2019						
2020	25	757				
2021					45	1755
2022					4	198

2.4 Tuning procedure

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

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

1. Set the standard error for the log of relative abundance indices (CPUE) to the standard deviation of a loess curve fitted to the original data - which will provide a more realistic estimate to that obtained from the original statistical analysis. SS-V3.30 then allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

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

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

For the age and length composition data:

3. Multiply the stage-1 (initial) sample sizes for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).
4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data using the 'Francis method' (Francis, 2011).
5. Repeat steps 2–4, until all are converged and stable (with proposed changes < 1%).

This procedure constitutes current best practice for tuning assessments.

2.5 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 ever since. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to a Tier level depending on the basis used for assessing stock status or exploitation level for that stock. Deepwater Flathead is assessed as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}, the default economic target of B_{MEY}. 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. For Deepwater Flathead the B_{MEY} value is 43% of B_0, as reported in Kompas et al. (2011), and therefore a 20:35:43 harvest control rule is used.

2.6 Retrospective analyses

A retrospective analysis was completed, starting from the most recent year of data, working backward in time and removing five successive years of data from the assessment. This analysis can highlight potential problems and instability in an assessment, or some features that appear from the data.

The severity of retrospective patterns can be quantified using a statistic called Mohn's rho, which is the average of the relative differences between an estimate from an assessment with a truncated time series and an estimate of the same quantity from an assessment using the full time series (Mohn, 1999; Hurtado-Ferro et al., 2015). Mohn's rho values are calculated for a range of effects, including SSB, recruitment, F and stock status. As a general rule values of Mohn's rho higher than 0.20 or lower than −0.15 are cause for concern in an assessment (Hurtado-Ferro et al., 2015).

2.7 Likelihood profiles

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

2.8 Jitter analyses

Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, initially a check on whether a better "optimal solution" may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or "jittered," simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 25 replications, modifying initial values by 10%.

2.9 Dynamic B0

A key output of a stock assessment (and the input to many HCRs) is an estimate of current stock status (or "depletion"). This is calculated by dividing the estimate of current biomass by a measure of unfished (or "virgin") biomass. Traditionally, stock assessments have assumed that, while environment conditions may vary, an unfished stock will fluctuate about an average level (referred to as "static B_0"). This assumption becomes increasingly untenable given climate change, which is leading to changes in biological parameters such as growth and the survival of eggs, larvae and juveniles. This has motivated the idea that stock status under changing environmental conditions should instead be defined as the ratio of current biomass to a measure of "current" unfished biomass ("dynamic B_0").

The biomass time-series (and hence the trend in stock status) using dynamic B_0 is calculated by projecting the population forward from its initial state without applying fishing mortality to calculate reference points, once an assessment has been conducted and the model parameters estimated. Importantly, this calculation assumes that recruitment is not influenced by fishing pressure and is only influenced by non-fishing related factors (such as environmental drivers).

2.10 Sensitivity tests

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

1. Fix M = 0.26 yr^{-1}.
2. Fix M = 0.22 yr^{-1}.
3. Fix steepness (h) at 0.85.
4. Fix steepness (h) at 0.65.
5. σ_R set to 0.8.
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 survey (CPUE) data.
12. Halve the weighting on the survey (CPUE) data.
13. Low Recruitment. Project with average of the last 10 year estimated recruitment deviations under fixed catch scenarios

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

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2024}: the female spawning biomass at the start of 2024/25.
3. SSB_{2024}/SSB_0: the female spawning biomass depletion level at the start of 2024/25.
4. RBC_{2024}: the recommended biological catch (RBC) for 2024/25.
5. $\text{RBC}_{2024\text{-}27}$: the mean RBC over the four years from 2024/25-2027/28.
6. $\text{RBC}_{\text{longterm}}$: the longterm RBC.

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

3 Results

3.1 The base case

3.1.1 Transition from the 2019 base case to the 2023 base case

The development of a preliminary base case, and a bridging analysis from the 2019 assessment (Tuck et al., 2019b), was presented at the October 2023 GABRAG meeting, including updating the version of Stock Synthesis and sequentially updating data (Tuck and Bessell-Browne, 2023). This bridging analysis is not repeated in this report. The October 2023 GABRAG agreed that the base cade model structure should now include the Danish seine fleet.

3.1.2 Parameter estimates

Figure 2 shows the estimated growth curve for female and male Deepwater Flathead. The rate of natural mortality, *M*, is estimated in the base-case model, with the estimated value being *M*=0.24 yr^{-1}; the model outcomes are sensitive to this parameter and a likelihood profile was conducted, 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.

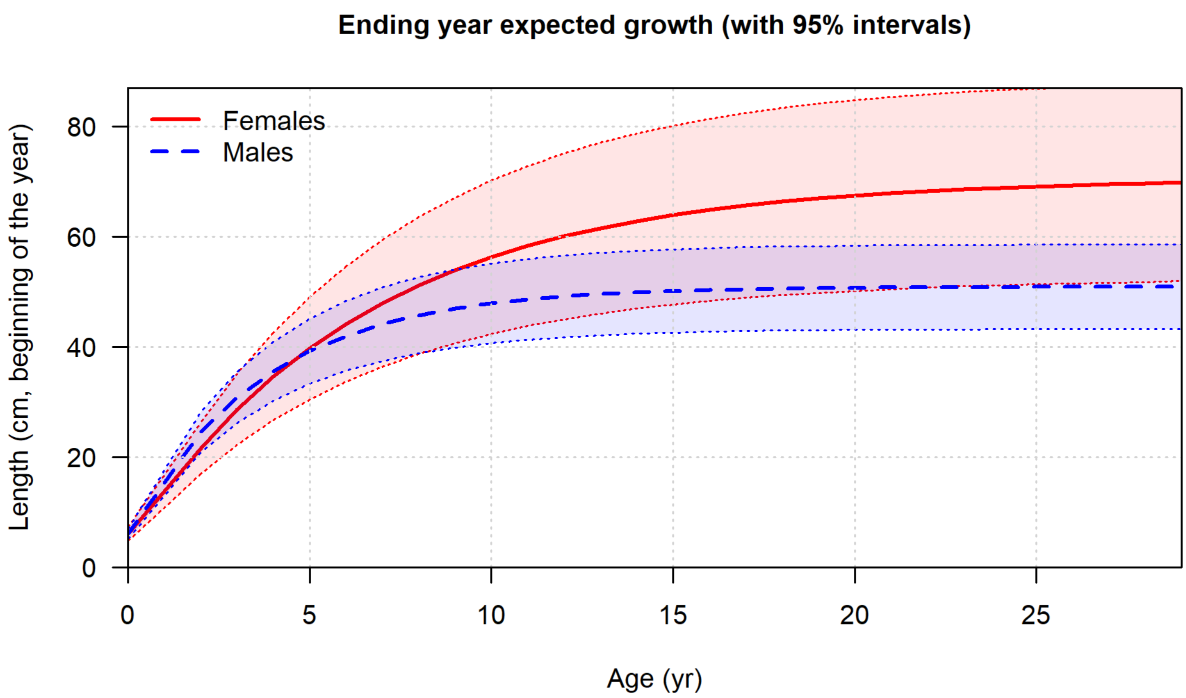


Figure 2. The model estimated growth curves for the base case Deepwater Flathead assessment.

The estimate of the parameter that defines the initial numbers (and biomass), ln*(R0)*, is 9.498 for the base case.

Selectivity is assumed to be logistic for the trawl, Danish seine and FIS fleets (Figure 3). 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).

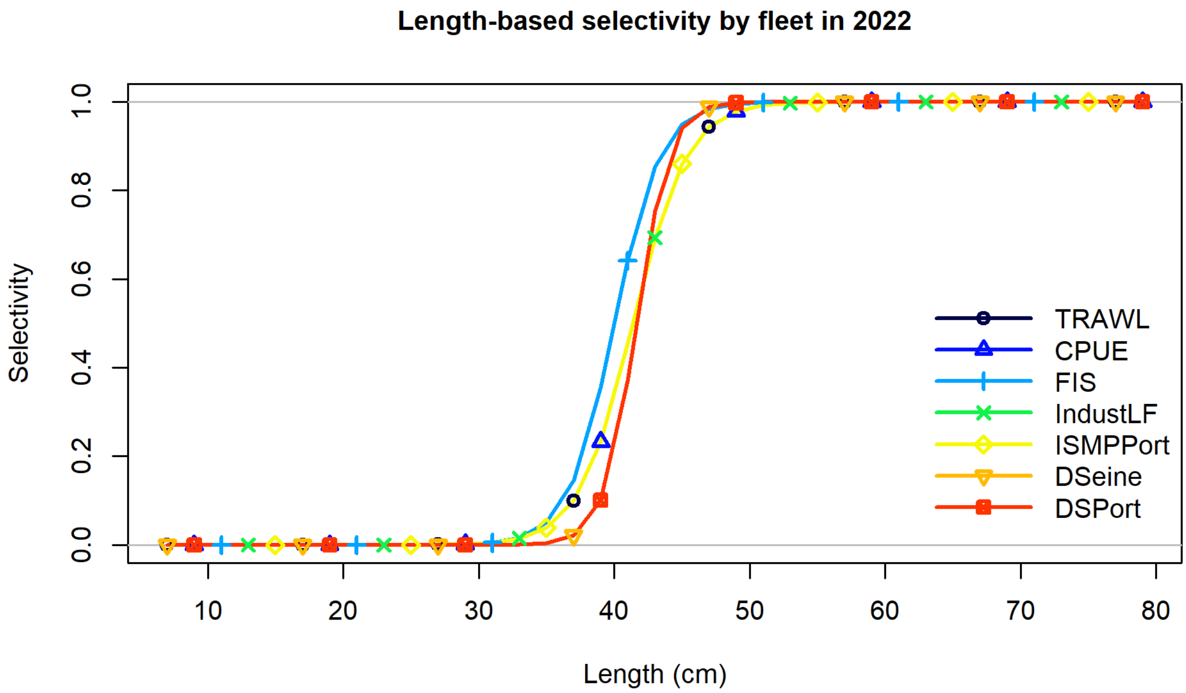


Figure 3. Estimated selectivity curves for Deepwater Flathead. There are three different selectivity patterns, with (i) industry, port and onboard trawl fleets having the same selectivity, (ii) Danish seine port and onboard, and (iii) the FIS fleet having separate estimated selectivity.

3.1.3 Fits to the data

Results show reasonably good fits to the catch rate data, length data and conditional age-at-length data. The fits to the FIS abundance indices show a poor fit to the final years, which may also have influenced the under-fit to the initial 5 years of FIS indices (Figure 4). The base-case model is able to fit the aggregated retained length-frequency distributions very well (Figure 5). Length composition fits by year and fleet are provided in the Appendix.

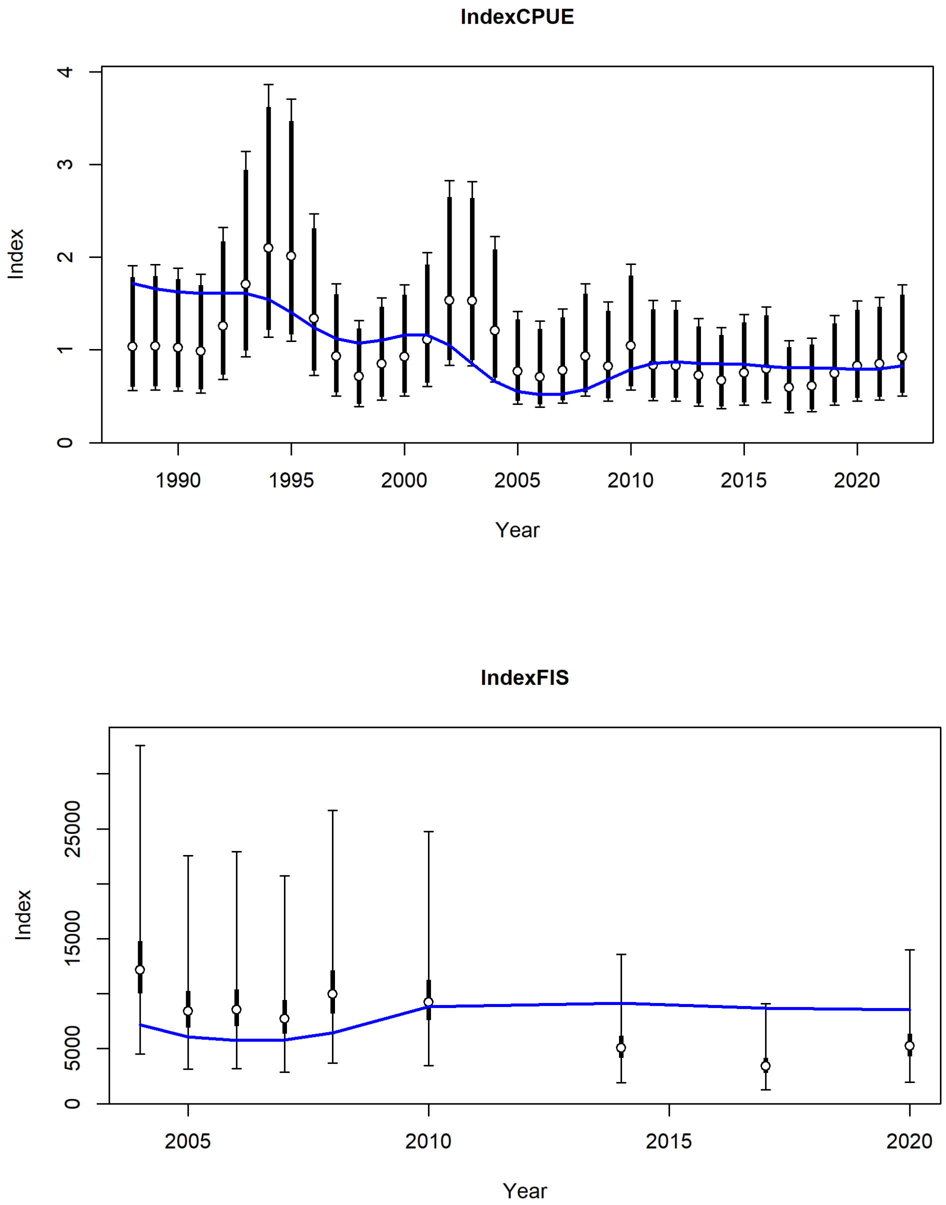


Figure 4. Fits to the trawl CPUE (top) and GABFIS (bottom) for Deepwater Flathead.

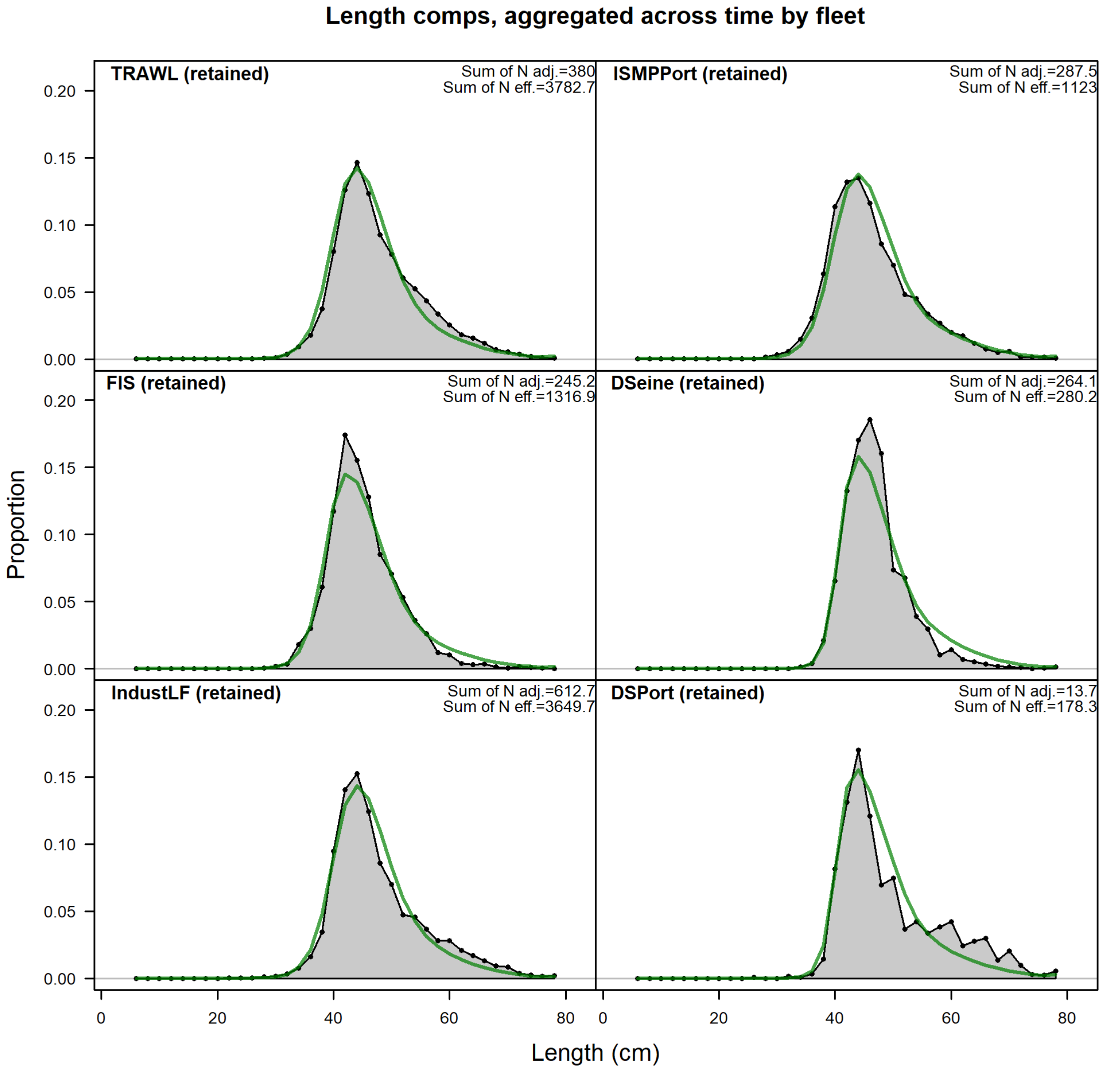


Figure 5. Aggregated fits (all years combined) to the length compositions for Deepwater Flathead displayed by fleet.

3.1.4 Assessment outcomes

This assessment estimates that the projected 2024/25 spawning stock biomass will be 44% of virgin stock biomass (projected assuming 2022/23 catches in 2023/24; Figure 6). The base case assessment estimated the unexploited female spawning biomass, SSB_0, to be 9,918t. Recruitments show a fluctuating pattern, with a recent period of below average recruitment from since 2010 (Figure 7).

Figure 8 shows a Kobe plot for the base case analysis. This plot shows a time series of spawning biomass plotted against spawning potential ratio, which provides a measure of overall fishing mortality, and shows the stepwise movement in this space from the start of the fishery, in the bottom right corner, when there was low fishing mortality and high biomass, to the present day where the biomass is near the target (to the left of the vertical dashed line) and the fishing mortality is below the target fishing level (below the horizontal dashed line).

The 2024/25 recommended biological catch (RBC) under the 20:35:43 harvest control rule is 1,220 t and the long-term yield (assuming average recruitment in the future) is 1,199 t. The average RBC over the four-year period 2024/25 – 2027/28 is 1,209 t (Table 9).

Table 9. Yearly projected RBCs (tonnes) under the 20:35:43 harvest control rule.

Year	RBC	Status
2024	1,220	0.44
2025	1,211	0.44
2026	1,204	0.44
2027	1,200	0.43
Average (2024-27)	1,209	

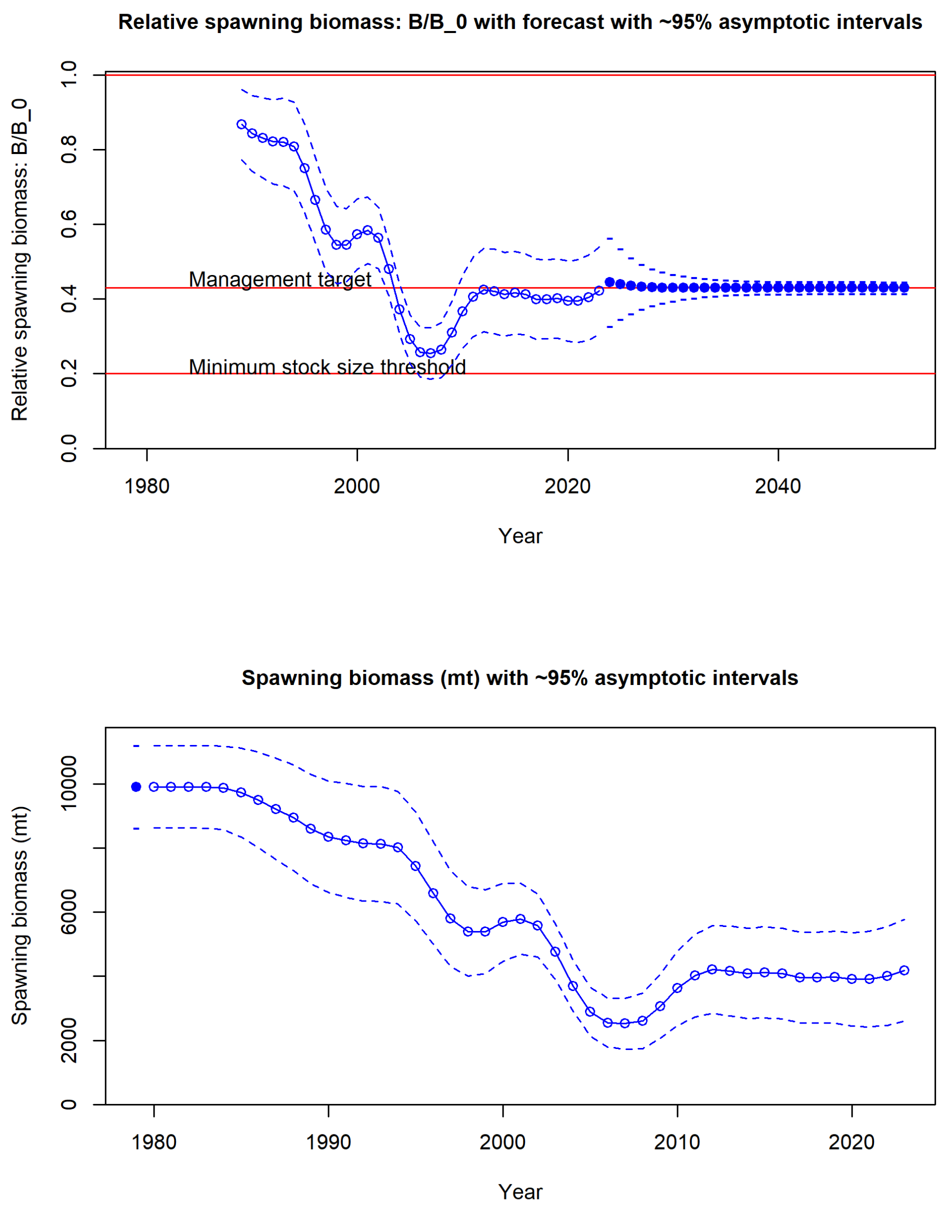


Figure 6. The projected relative spawning biomass trajectory (top) and magnitude of spawning biomass (bottom) for the Deepwater Flathead base case assessment.

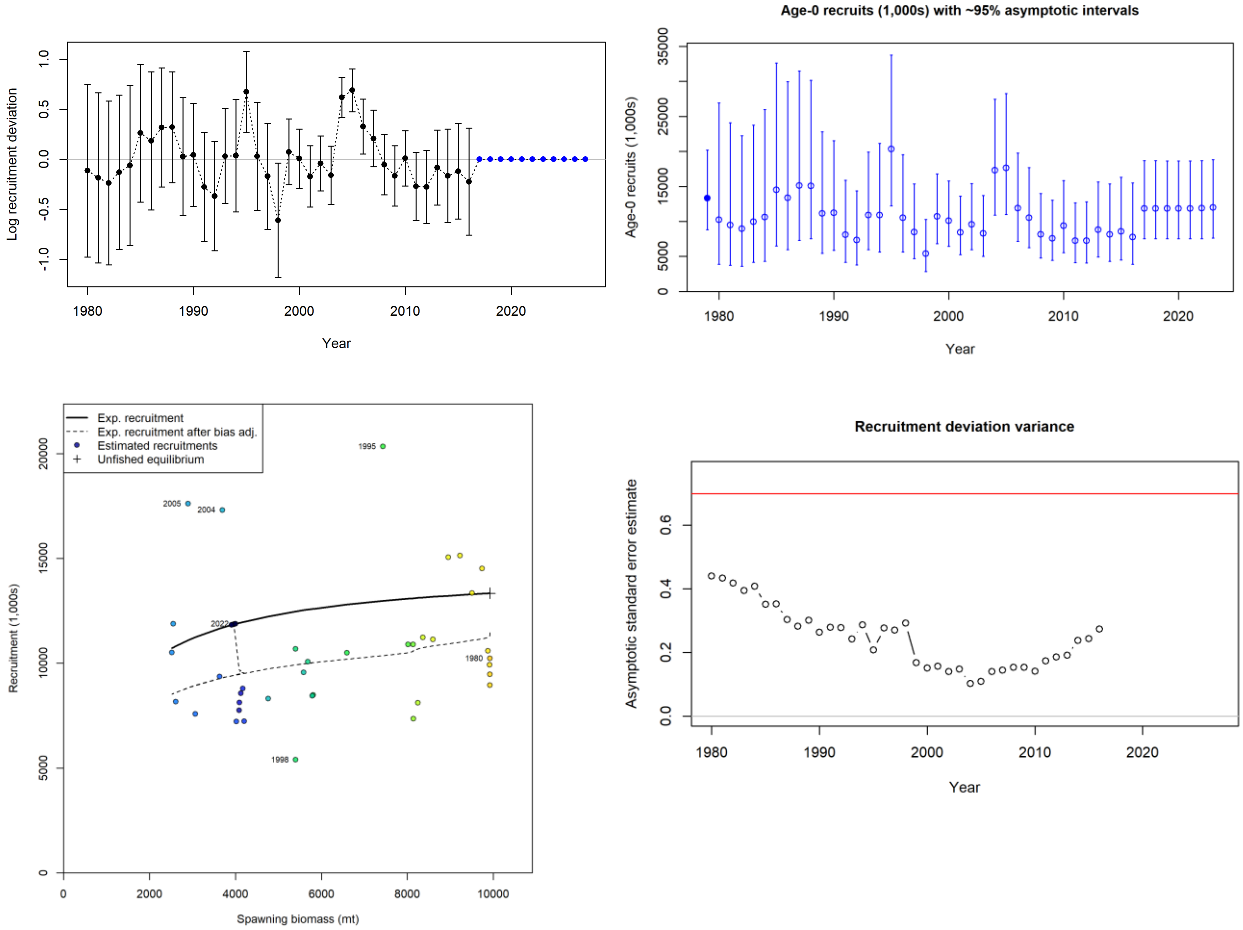


Figure 7. Recruitment deviations (top left) and absolute recruitment (top right) estimates with confidence intervals, stock recruitment curve (bottom left) and recruitment deviation variance check (bottom right) for the Deepwater Flathead base case.

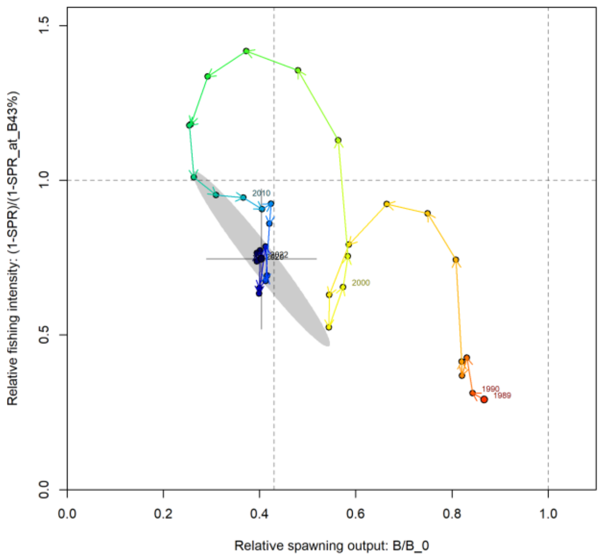


Figure 8. Phase plot of biomass vs SPR ratio for the Deepwater Flathead base case.

3.2 Retrospectives

A retrospective analysis for absolute spawning biomass is shown in Figure 9, with the base case model in dark blue, and then successive years of data removed back to 2017 (shown in red). The same analysis is plotted in terms of relative spawning biomass in Figure 10 and estimated recruitment is shown in Figure 11. With the exception of the 2017 retrospective assessment estimating the stock to be ~50% unfished spawning biomass in 2017, the 2018–2022 retrospective assessments consistently estimate current spawning biomass to be ~40% of the unfished level. Therefore the retrospective analyses do not reveal any pathological patterns or apparent biases in the estimates which provides additional confidence in the stability of this assessment.

Mohn's rho estimates for SSB, recruitment, F and stock status are presented in Table 10 with estimates within the acceptability criteria (between -0.15 and 0.20).

Table 10. Mohn's rho estimates for the base case.

Parameter	Estimate
SSB	0.16
Recruitment	0.03
F	-0.14
Stock status	0.13

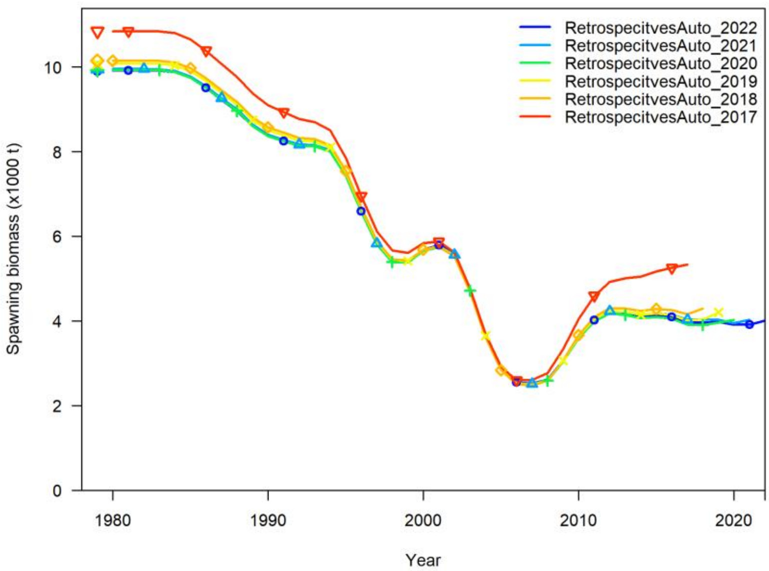


Figure 9. Retrospectives for absolute spawning biomass for Deepwater Flathead, with the base case assessment shown (blue) and then successive years of data removed back to 2017 (red).

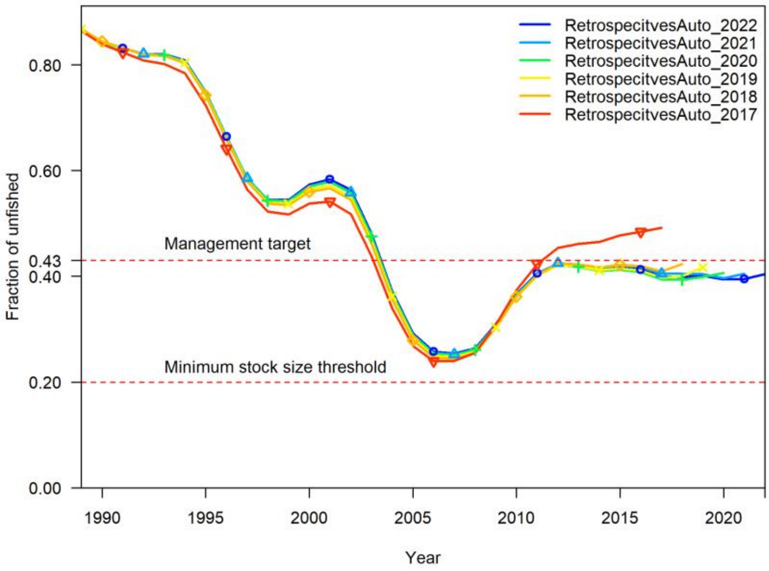


Figure 10. Retrospectives for relative spawning biomass for Deepwater Flathead, with the base case assessment shown (blue) and then successive years of data removed back to 2017 (red).

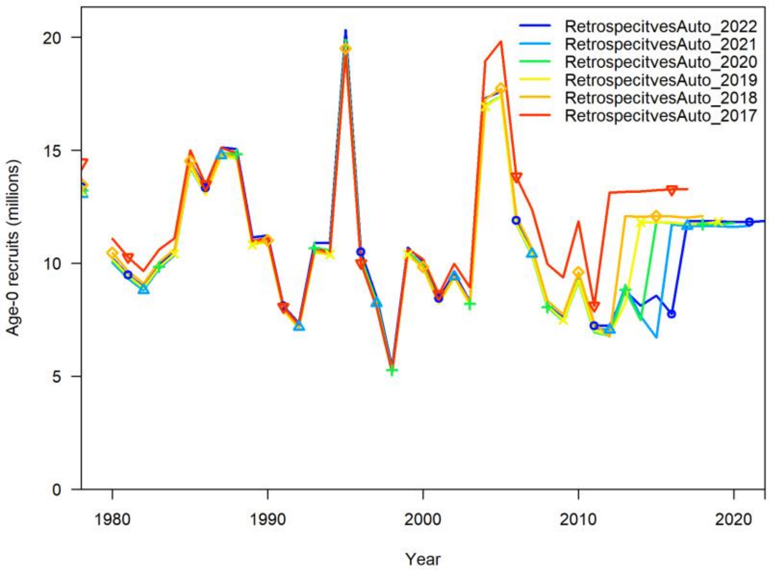


Figure 11. Retrospectives for recruitment for Deepwater Flathead, with the base case assessment shown (blue) and then successive years of data removed back to 2017 (red).

3.3 Likelihood profiles

Likelihood profiles for key parameters of interest (such as natural mortality (M), steepness (h) and virgin spawning biomass) were provided in Tuck and Bessell-Browne (2023) for the preliminary agreed base case. As a new model structure was agreed at the October 2023 GABRAG that now includes a Danish seine fleet, only a profile on M is provided here (Figure 12). The index and length data suggest a higher value for natural mortality, whereas the age data suggest a lower value. The confidence intervals for natural mortality range between 0.21 and 0.275 yr^{-1}. The estimated value is 0.24 yr^{-1}.

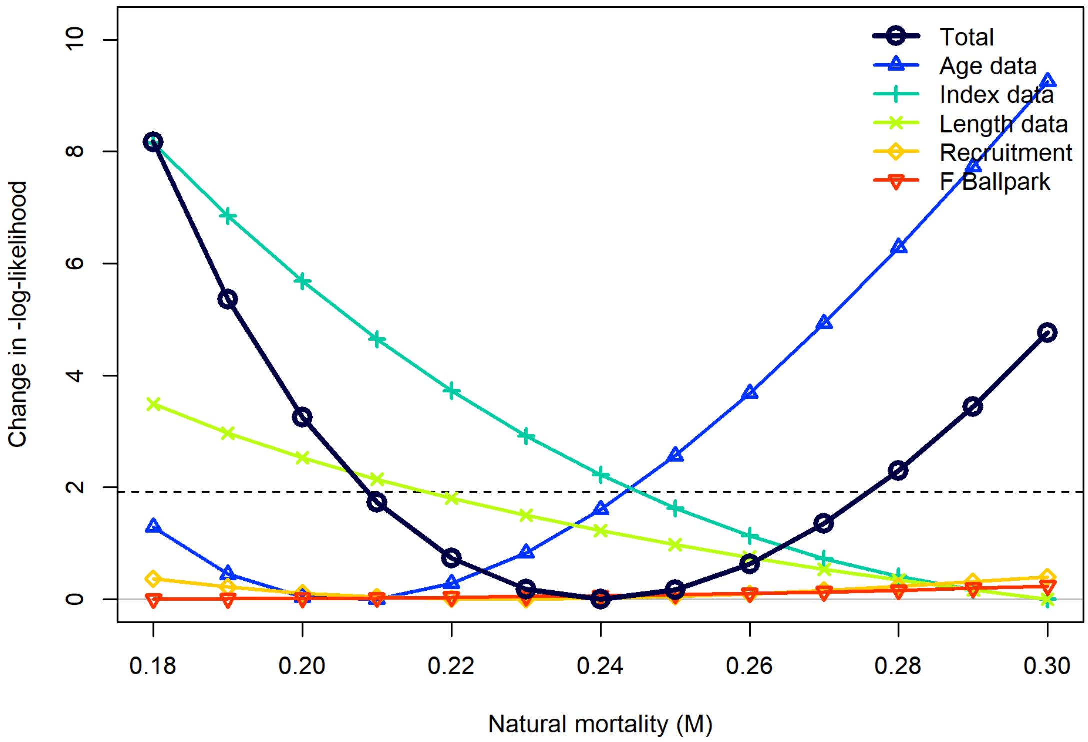


Figure 12. The likelihood profile for natural mortality.

3.4 Jitter

For the base case, 21 of the 25 jitter replicates found the same optimum solution, with a negative log-likelihood of 944.1. The remaining four replicates found worse 'optimal' solutions with a greater negative log-likelihood (Figure 13).

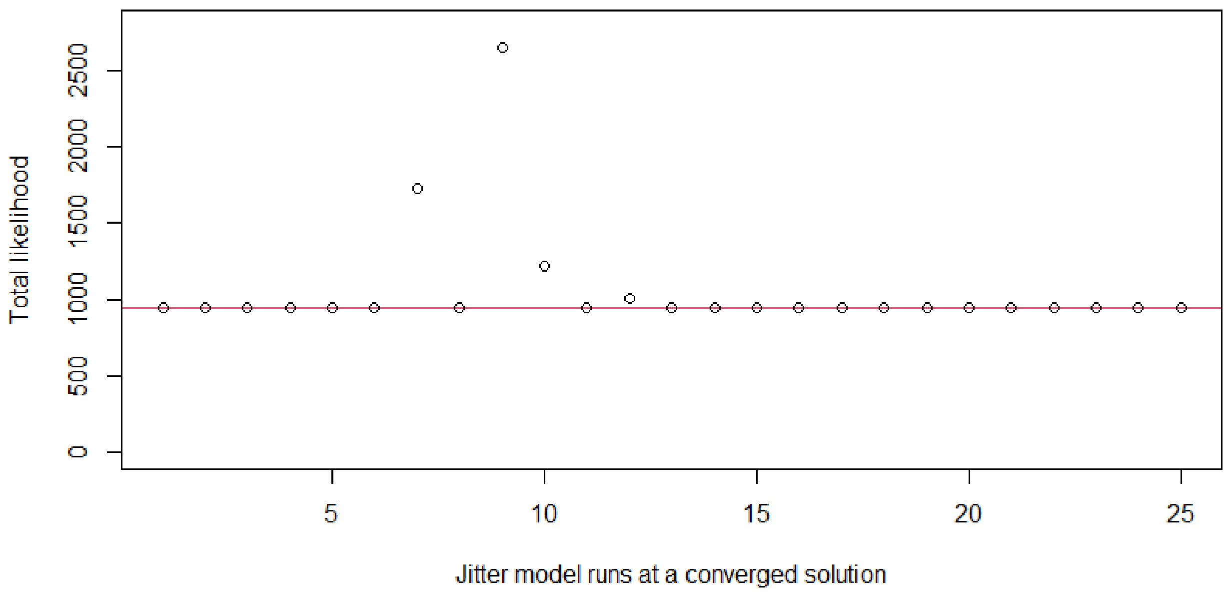


Figure 13. Total log-likelihood estimates from a jitter analysis for Deepwater Flathead.

3.5 Dynamic B_0

The Dynamic B_0 (or $B_{unfished}$) time series illustrated in Figure 14 is relatively flat (blue line) indicating that there likely has not been a substantial influence of the environment on this stock (or its recruitment).

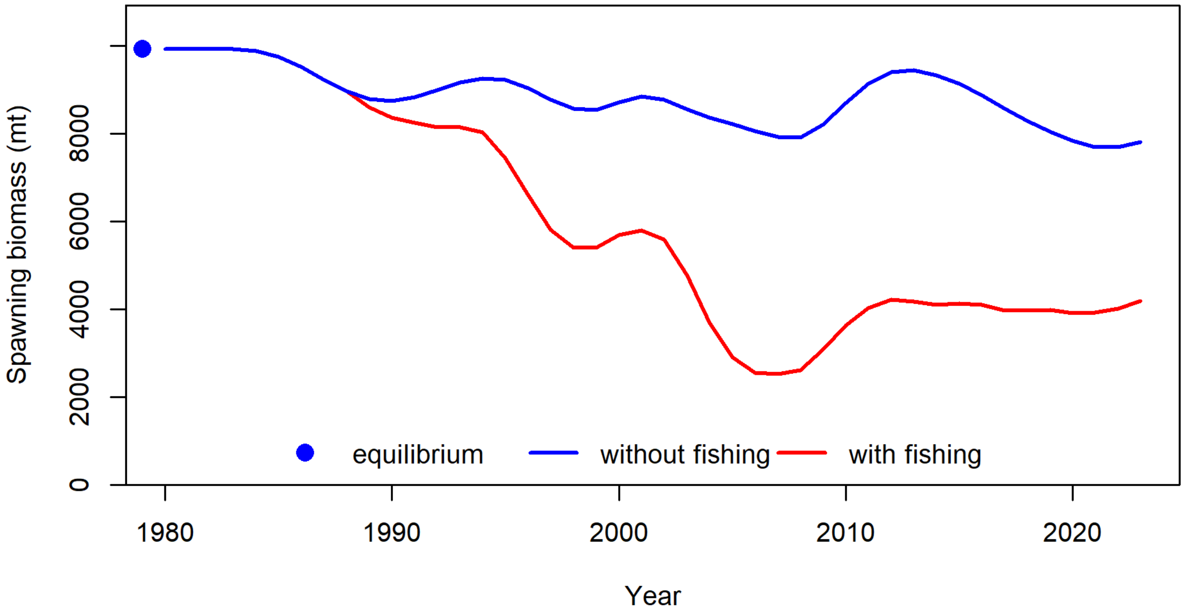


Figure 14. The estimated spawning stock biomass (SSB) trajectory (red), static B_0 (blue circle) and Dynamic B_0 (blue) for Deepwater Flathead.

3.6 Sensitivity tests and alternative models

3.6.1 Standard sensitivities

Results of the sensitivities to the potential base case are listed in Table 11. The usual set of sensitivities are provided (which includes sensitivities on mortality, steepness, σ_R and halving and doubling the weighting on length, age and index data). Results are not overly sensitive to varying key parameters, with depletion estimates ranging between 40% and 49% of virgin spawning biomass.

Unweighted likelihood components for the base case and differences for the sensitivities are shown in Table 12. This table tends to show that for most alternatives, the fit to the data is degraded by moving away from base case model values or weighting schemes.

3.6.2 Low recruitment scenario

As model estimates of recruitment deviations showed 8 of the last 10 years were below average, the October 2023 GABRAG asked for a low recruitment scenario to be conducted, whereby the average of the last 10 years (2007-2016) estimated recruitment deviations (-0.11365) is used from the first year of non-estimated recruitments (2017 onwards) (Figure 15). Fixed catch scenarios are then projected under the low recruitment scenario; chosen between current catches and the 2024 RBC (Figure 16). Projections illustrate that fixed catches of approximately 940 t will maintain the stock near the target of 43% of virgin spawning biomass under the assumed future low recruitment.

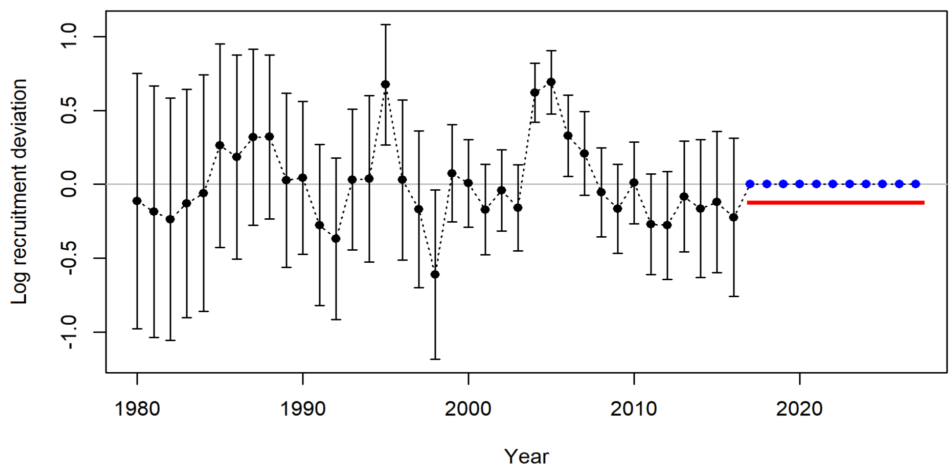


Figure 15. Estimated recruitment deviations from the base case model and the 10-year average (2007-2016) used in low recruitment projections (red).

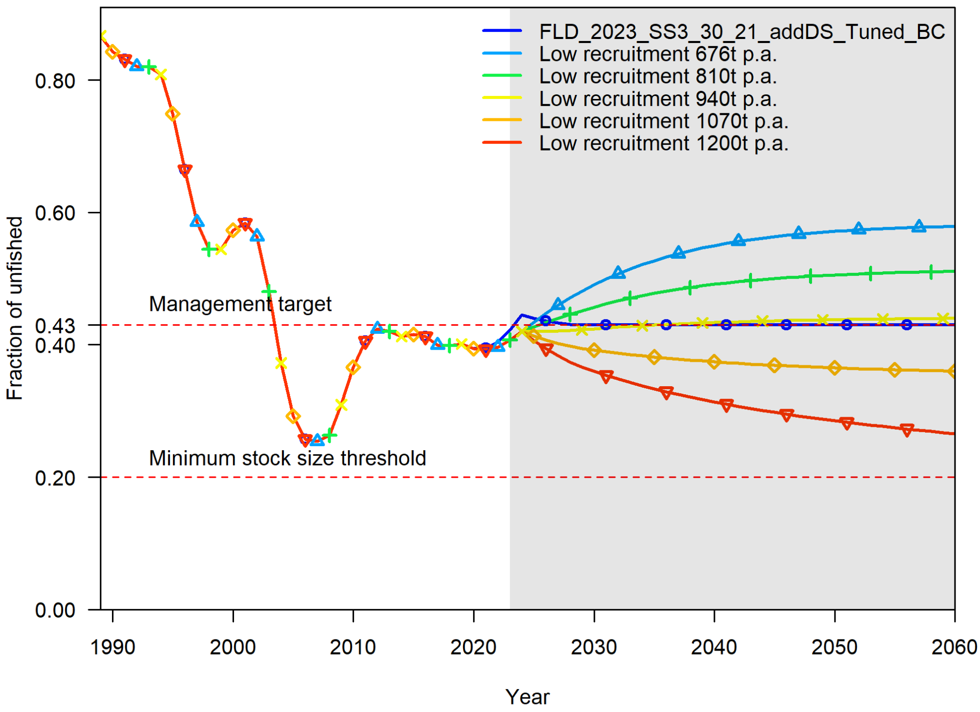


Figure 16. The relative spawning biomass trajectory for the base case model (navy blue; average recruitment) and low recruitment scenarios under different fixed annual catches.

4 Discussion

The 2023 base case assessment of Deepwater Flathead included Danish seine as a separate fleet for the first time. This entailed the inclusion of catches from this fleet from 2010 onwards. Lengths from port and onboard sampling and ages from Danish seine were also included for the first time. There were however, few years of age sampling and sampling should continue to ensure data are adequate to cover this fleet. Likewise, there was not a relative index of abundance for Danish seine (e.g. CPUE). Generally, the model fit well to the input data from both fleets, although the fits to the most recent trawl GABFIS biomass values is poor and likely due to the observed increased bycatch of stingarees. Alternative mechanisms for fishery independent surveys of abundance should be explored for the key GAB stocks. The current estimated stock status is nonetheless near the agreed management target of 43% of virgin spawning biomass and has been since approximately 2011.

Fixed catch scenarios were projected under a low recruitment scenario (namely, recruitment deviations averaged over the last 10 years of estimated values), showing that fixed catches of approximately 940 t will maintain the stock near the target of 43% of virgin spawning biomass under the assumed future low recruitment.

Assessment outcomes:

The projected 2024/25 spawning stock biomass will be 44% of virgin female spawning biomass (projected assuming 2022/23 catches in 2023/24), compared to 45% for 2020/21 in the 2019 assessment.

For the base case model, the 2024/25 recommended biological catch (RBC) under the 20:35:43 harvest control rule is 1,220 t. The long-term RBC is approximately 1,199 t.

Table 11. Summary of results for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for the base case.

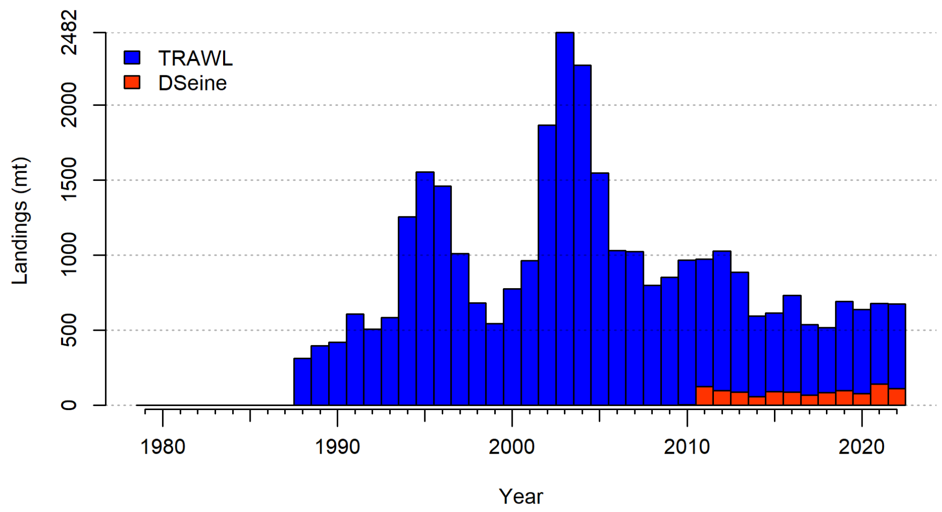
Sensitivity Scenario	SSB_0	SSB_{2024}	SSB_{2024}/SSB_0	RBC_{2024}	$RBC_{2024-27}$	$RBC_{longterm}$
base case (*M* 0.24, *h* 0.75)	9,918	4,413	0.44	1,220	1,209	1,199
M 0.26	9,919	3,962	0.40			
M 0.22	10,117	4,945	0.49			
h 0.85	9,919	3,962	0.40			
h 0.65	10,117	4,945	0.49			
$\sigma_R = 0.8$	9,323	4,188	0.45			
$\sigma_R = 0.6$	10,726	4,735	0.44			
wt x 2 length comp	9,396	4,343	0.46			
wt x 0.5 length comp	10,530	5,026	0.48			
wt x 2 age comp	10,168	4,850	0.48			
wt x 0.5 age comp	9,803	4,135	0.42			
wt x 2 index	10,404	4,696	0.45			
wt x 0.5 index	9,799	4,696	0.48			

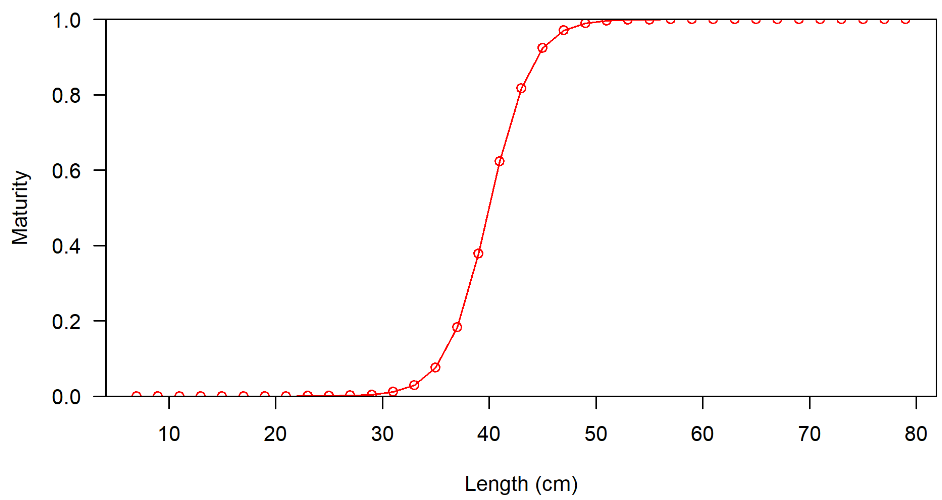
Table 12. Summary of likelihood components for the base-case and sensitivity tests. Likelihood components are unweighted, and cases 1-12 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Sensitivity Scenario	Likelihood TOTAL	Survey	Length comp	Age comp	Recruitment
base case (*M* 0.24, *h* 0.75)	944.11	-24.96	132.57	844.84	-8.45
M 0.22	0.73	1.50	0.57	-1.31	-0.01
M 0.26	0.63	-1.10	-0.48	2.09	0.08
h 0.65	0.18	-0.09	-0.15	0.24	0.16
h 0.85	-0.08	0.08	0.11	-0.18	-0.09
σ_R = 0.6	-4.52	-0.38	-0.23	0.14	-4.05
σ_R = 0.8	4.45	0.61	0.19	-0.06	3.70
wt x 2 CPUE	5.52	-11.98	-0.64	17.15	1.10
wt x 0.5 CPUE	1.64	6.95	0.53	-5.65	-0.09
wt x 2 length comp	3.11	-0.25	-7.52	11.31	-0.32
wt x 0.5 length comp	2.15	0.92	8.08	-7.15	0.42
wt x 2 age comp	5.21	8.14	10.30	-13.77	0.66
wt x 0.5 age comp	7.16	-10.35	-7.24	24.71	0.15

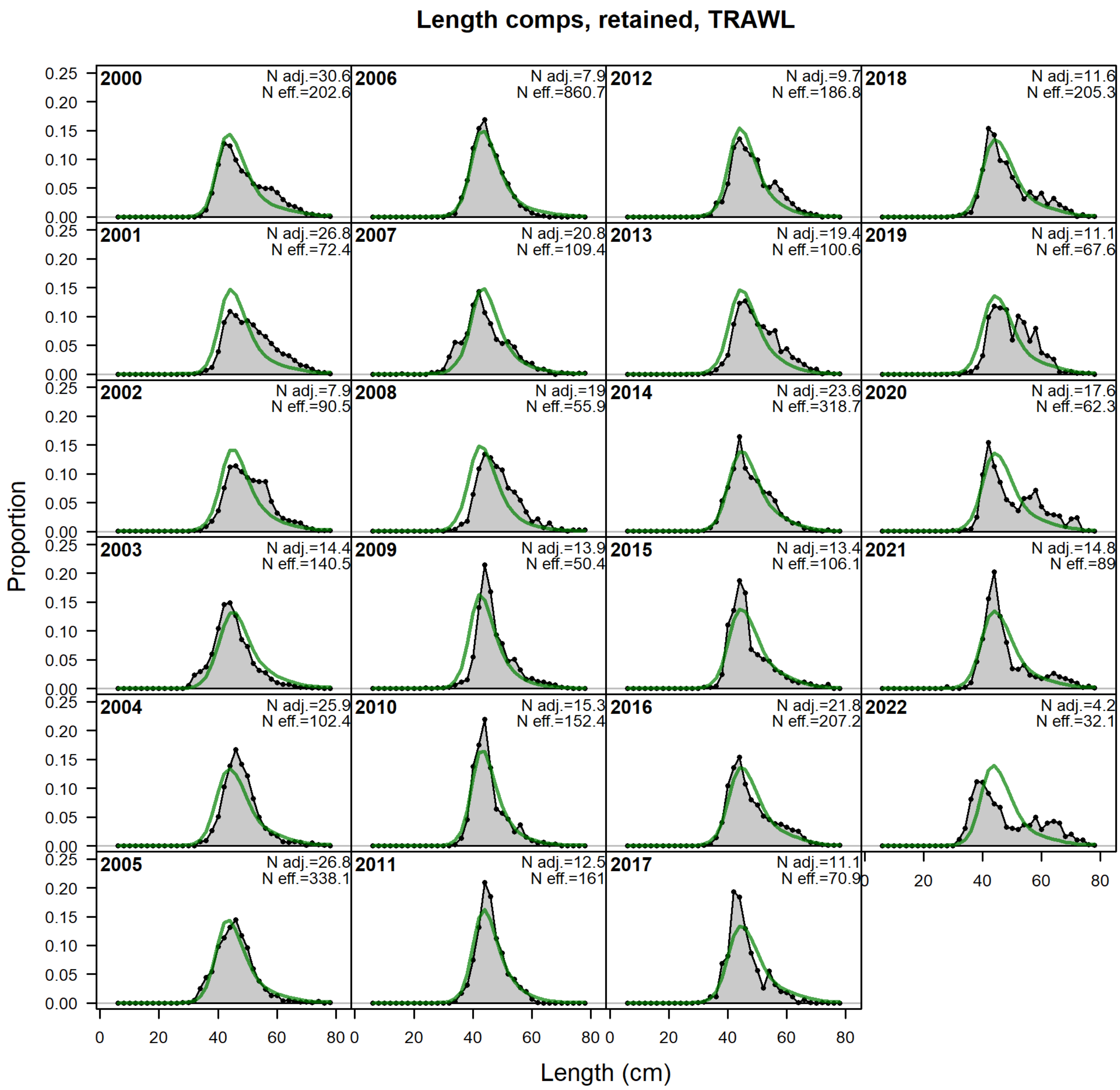
Appendix A

A.1 Base case diagnostics

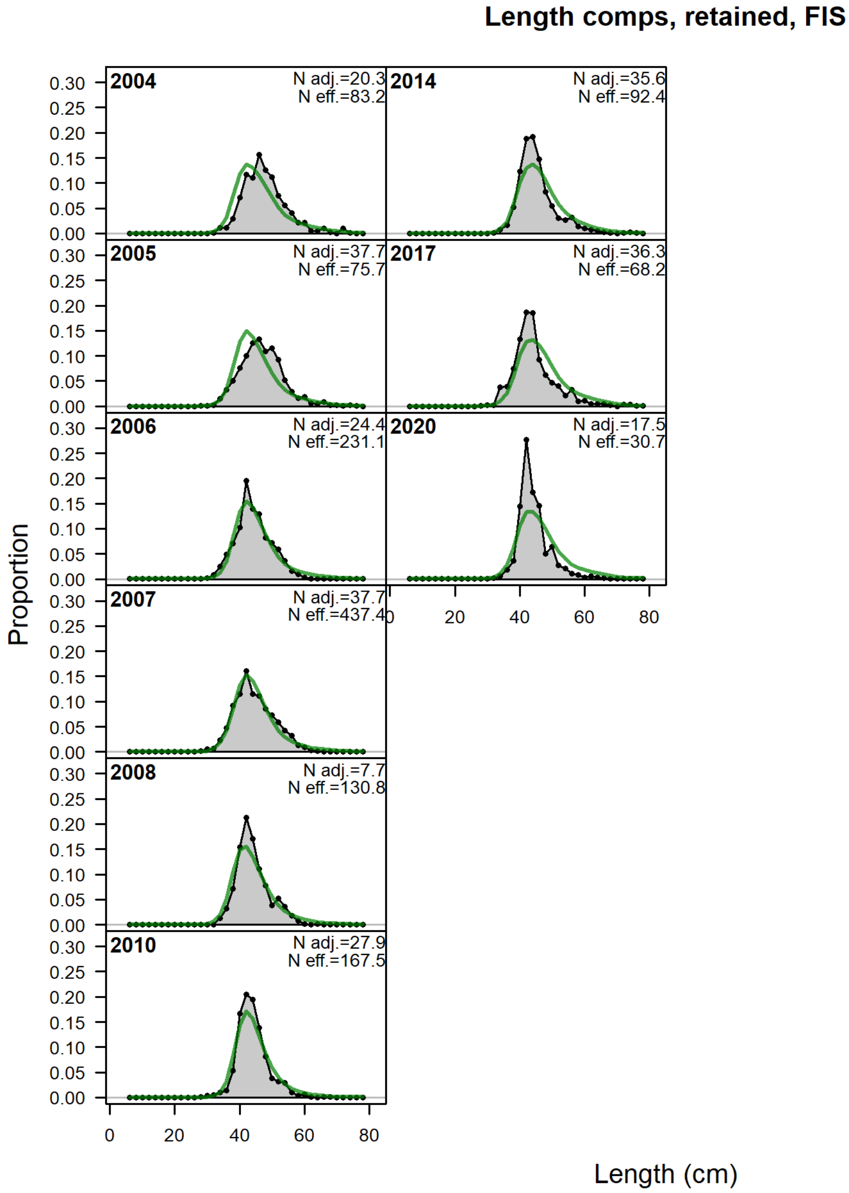




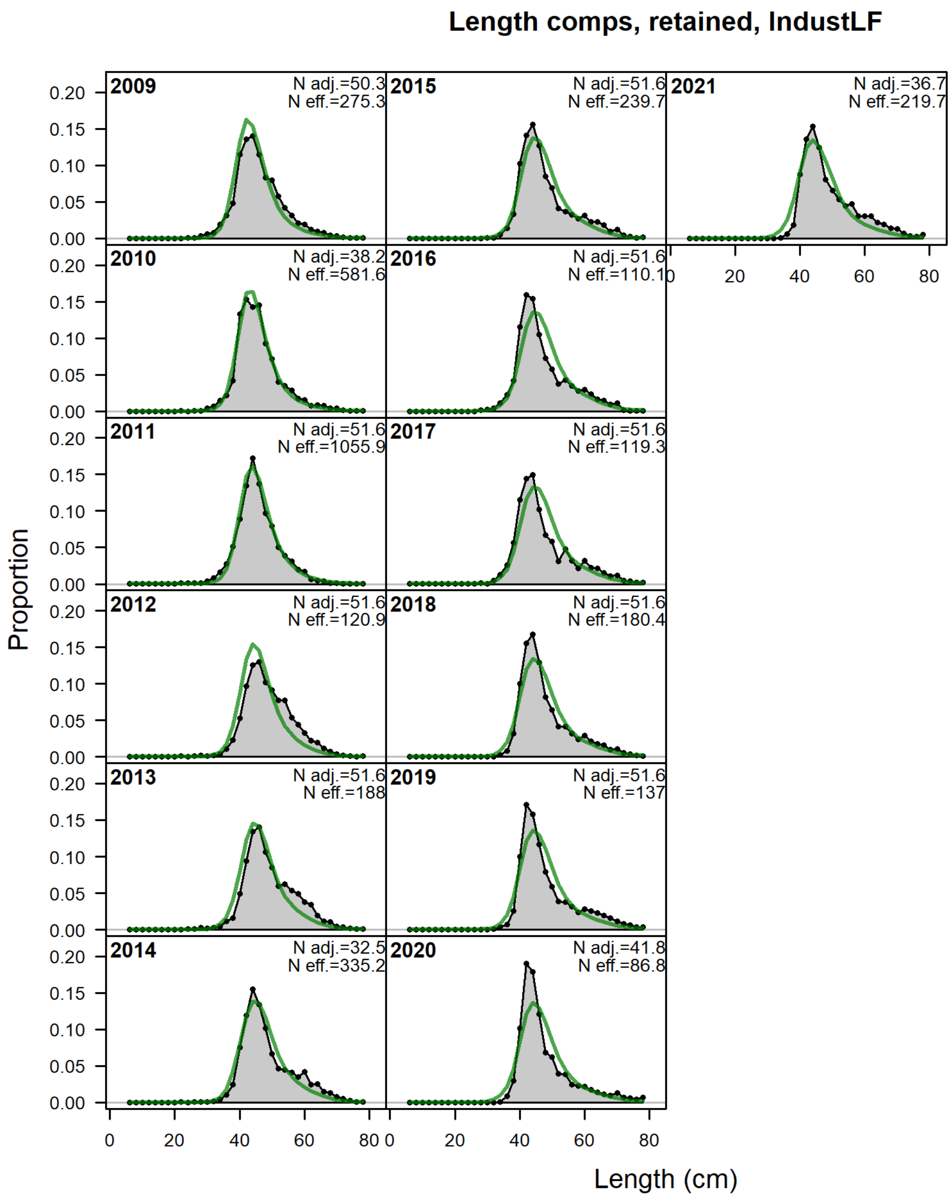
Apx Figure A.1 Landings and maturity for Deepwater Flathead.



Apx Figure A.2 Deepwater Flathead length composition fits: retained trawl onboard.

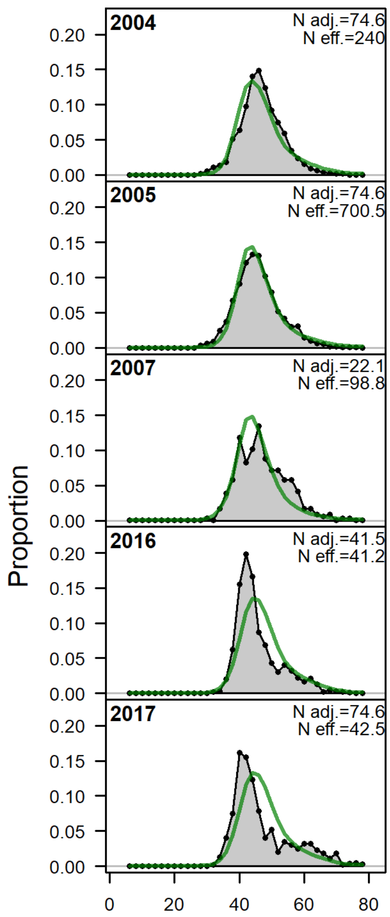


Apx Figure A.3 Deepwater Flathead length composition fits: FIS retained.



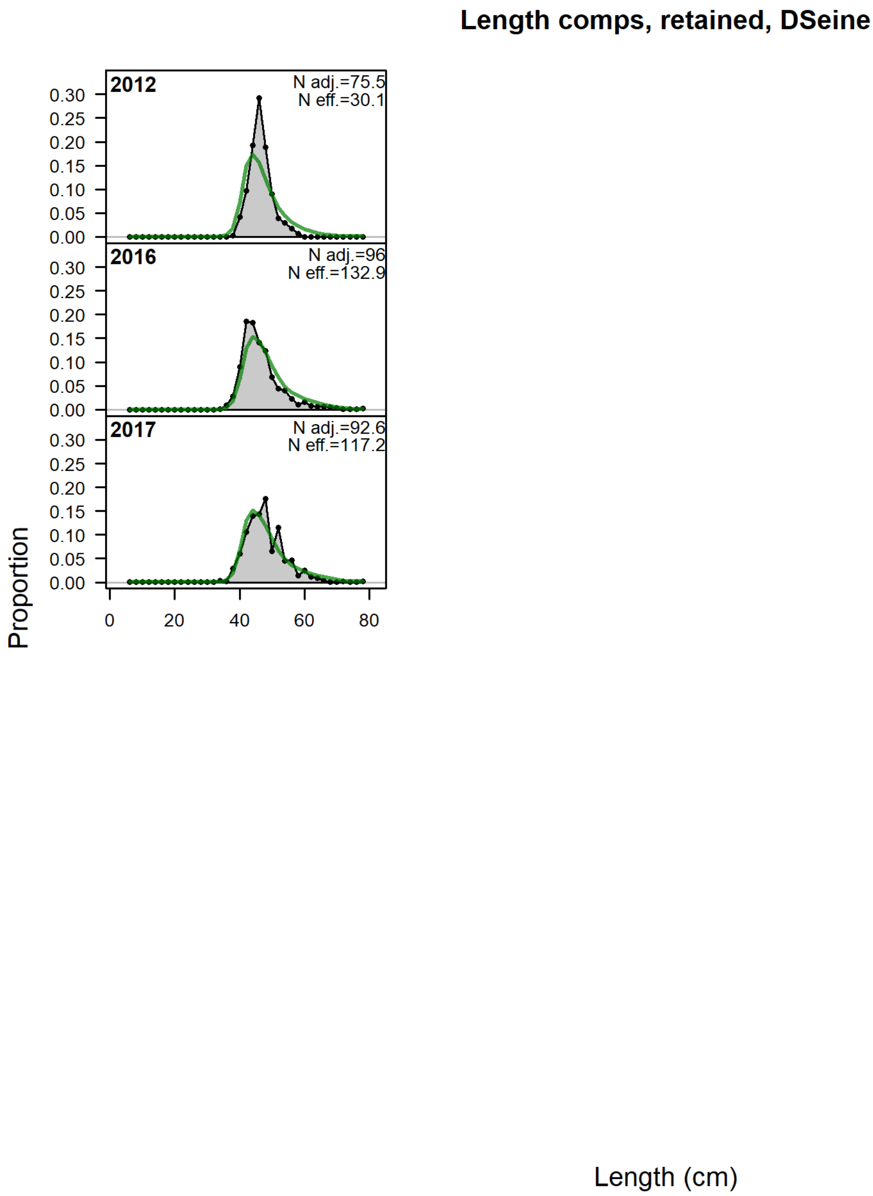
Apx Figure A.4 Deepwater Flathead length composition fits: Industry lengths.

Length comps, retained, ISMPPort

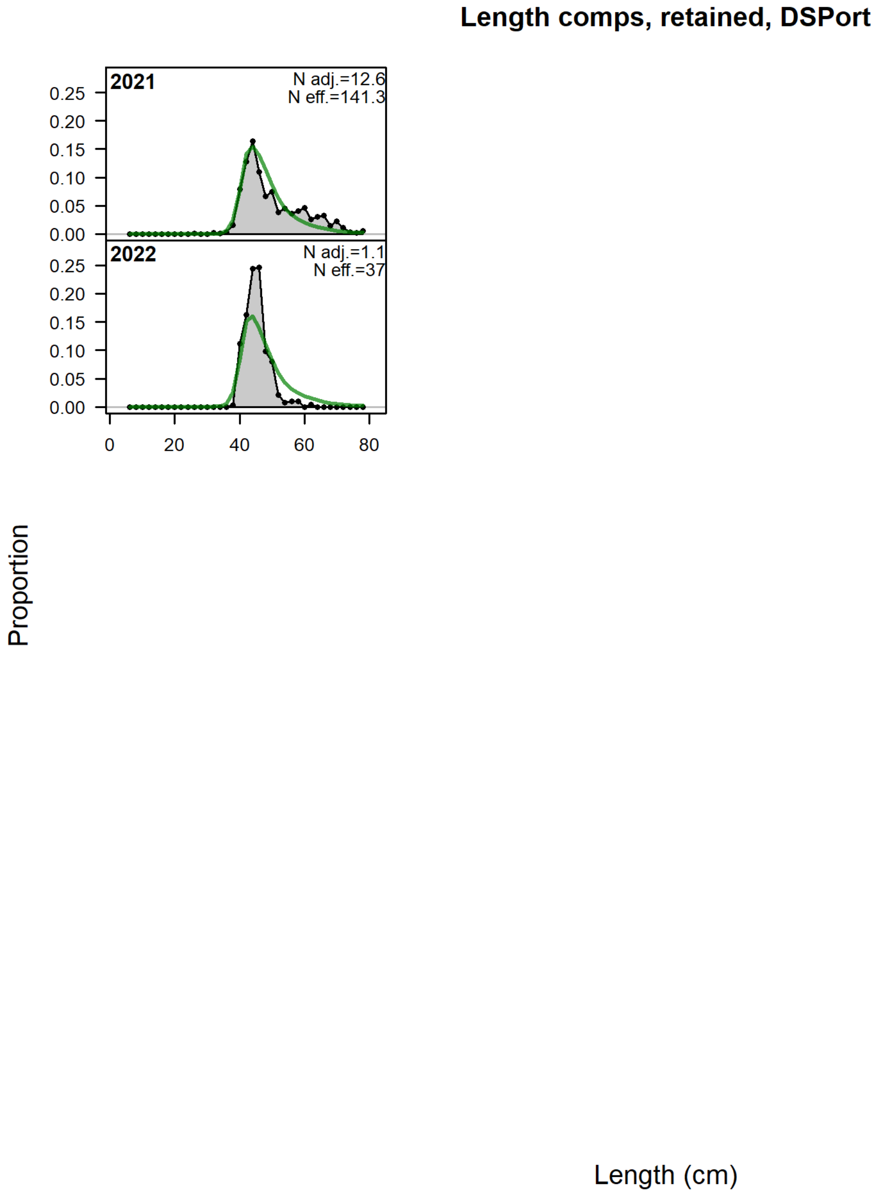


Length (cm)

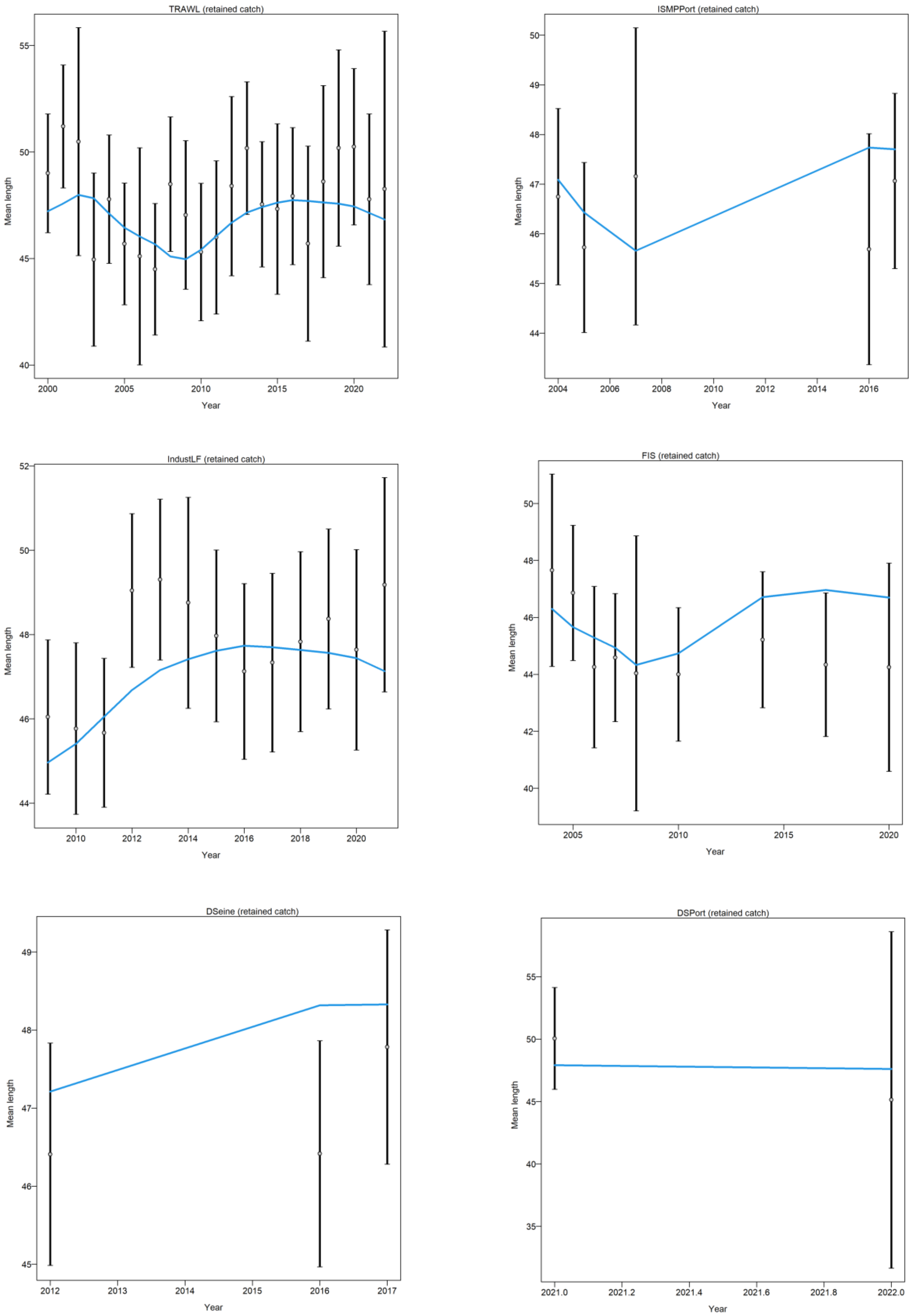
Apx Figure A.5 Deepwater Flathead length composition fits: Port.



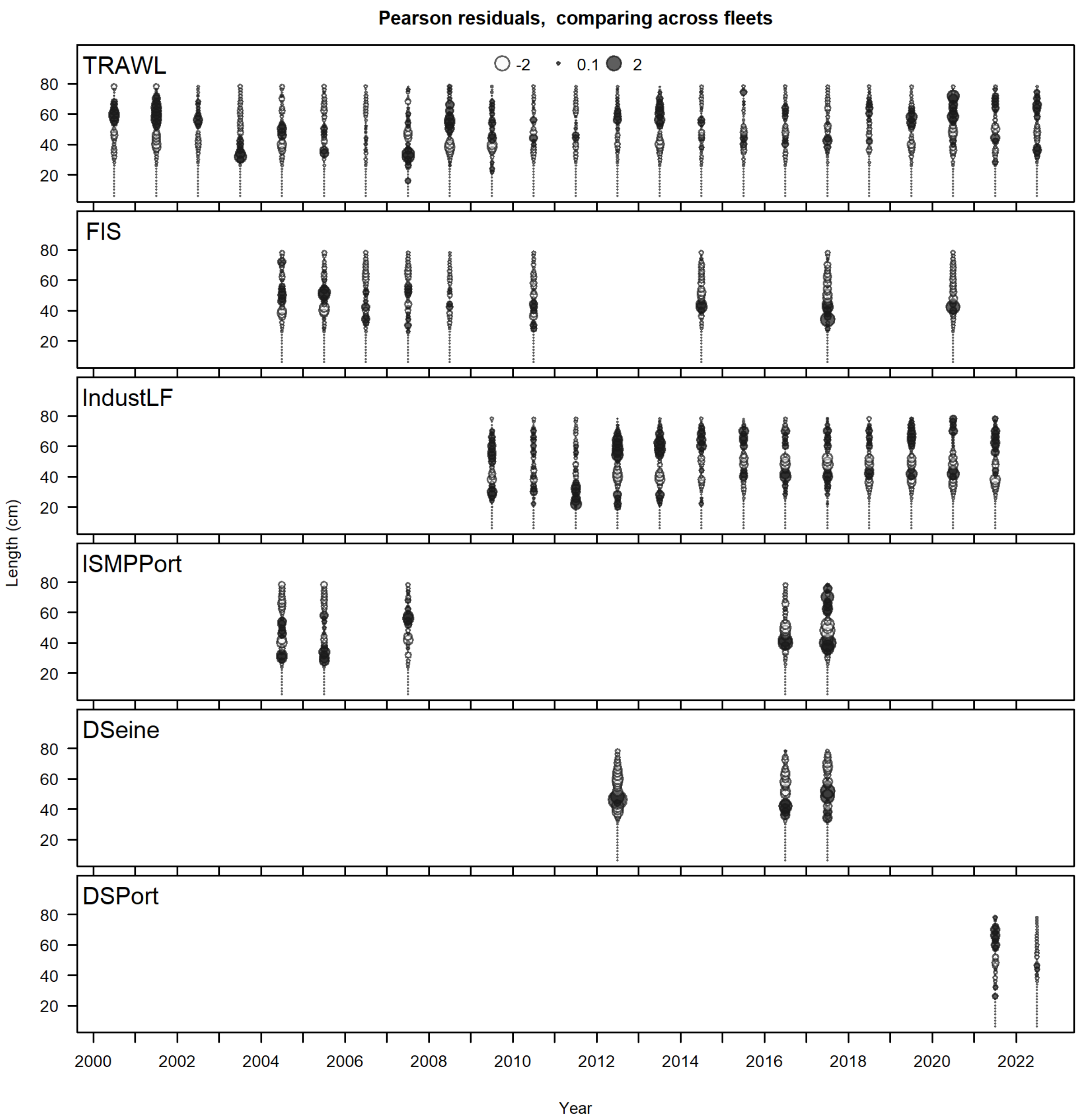
Apx Figure A.6 Deepwater Flathead length composition fits: Danish seine onboard.



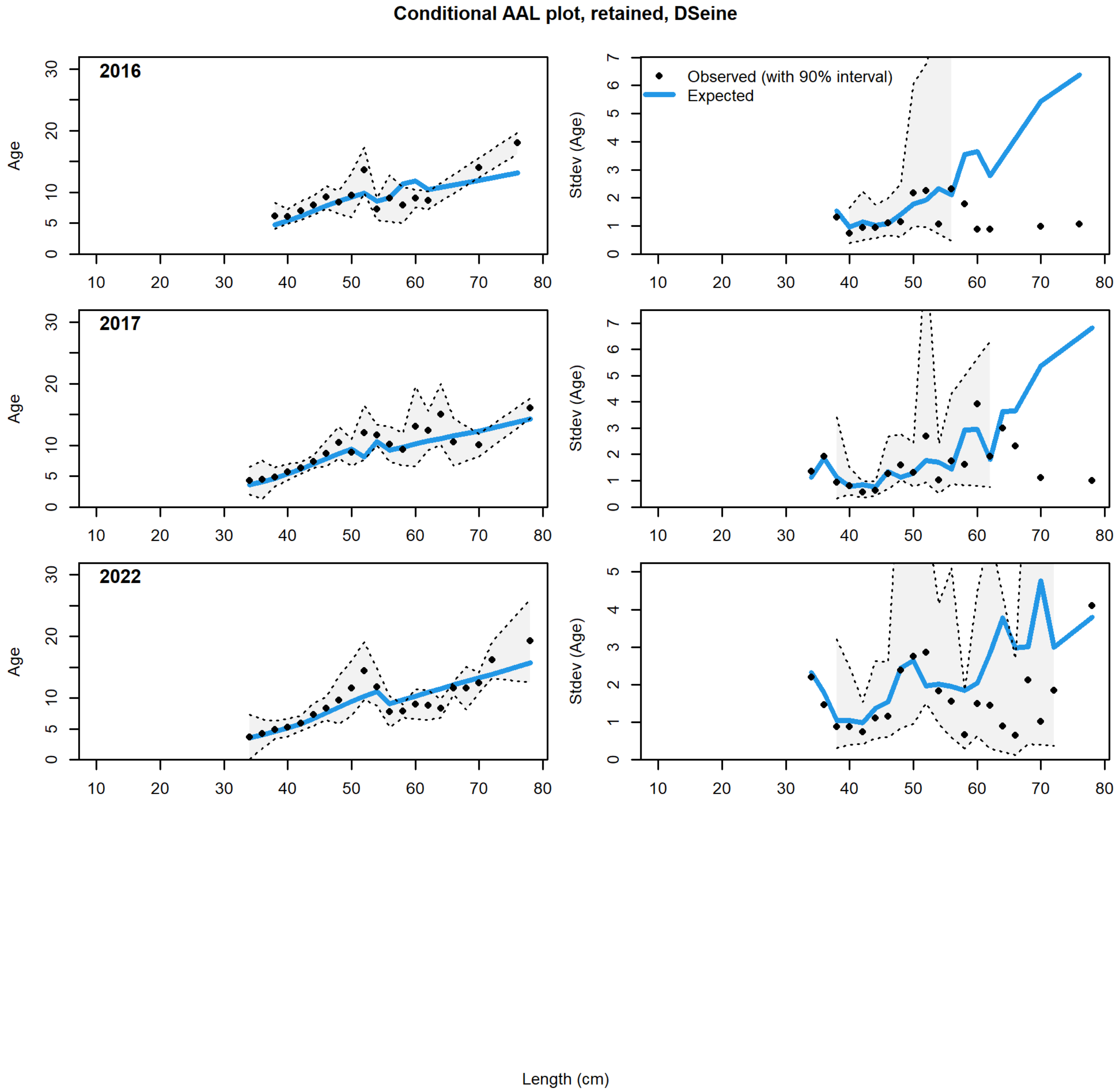
Apx Figure A.7 Deepwater Flathead length composition fits: Danish seine port.



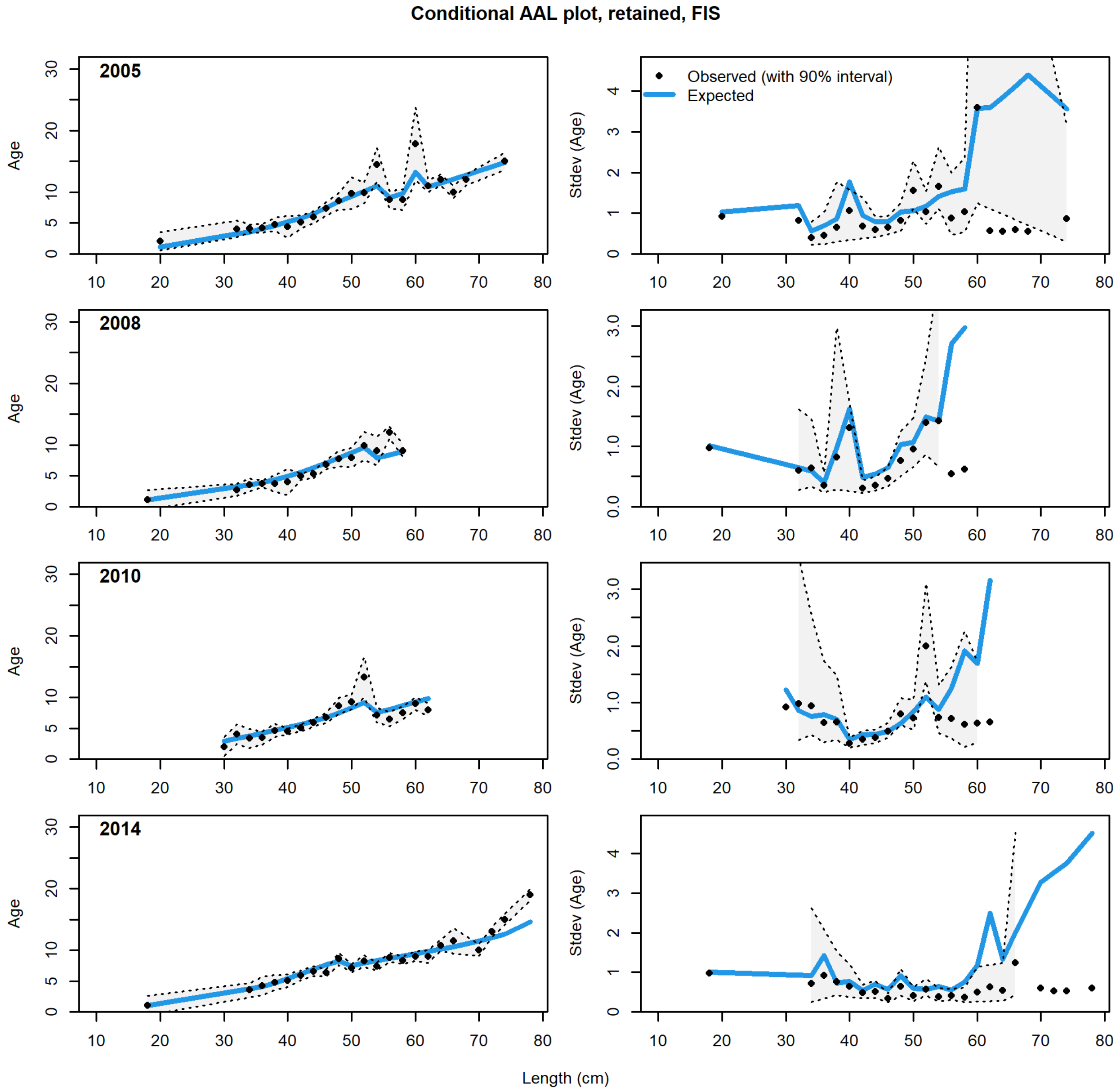
Apx Figure A.8 Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.



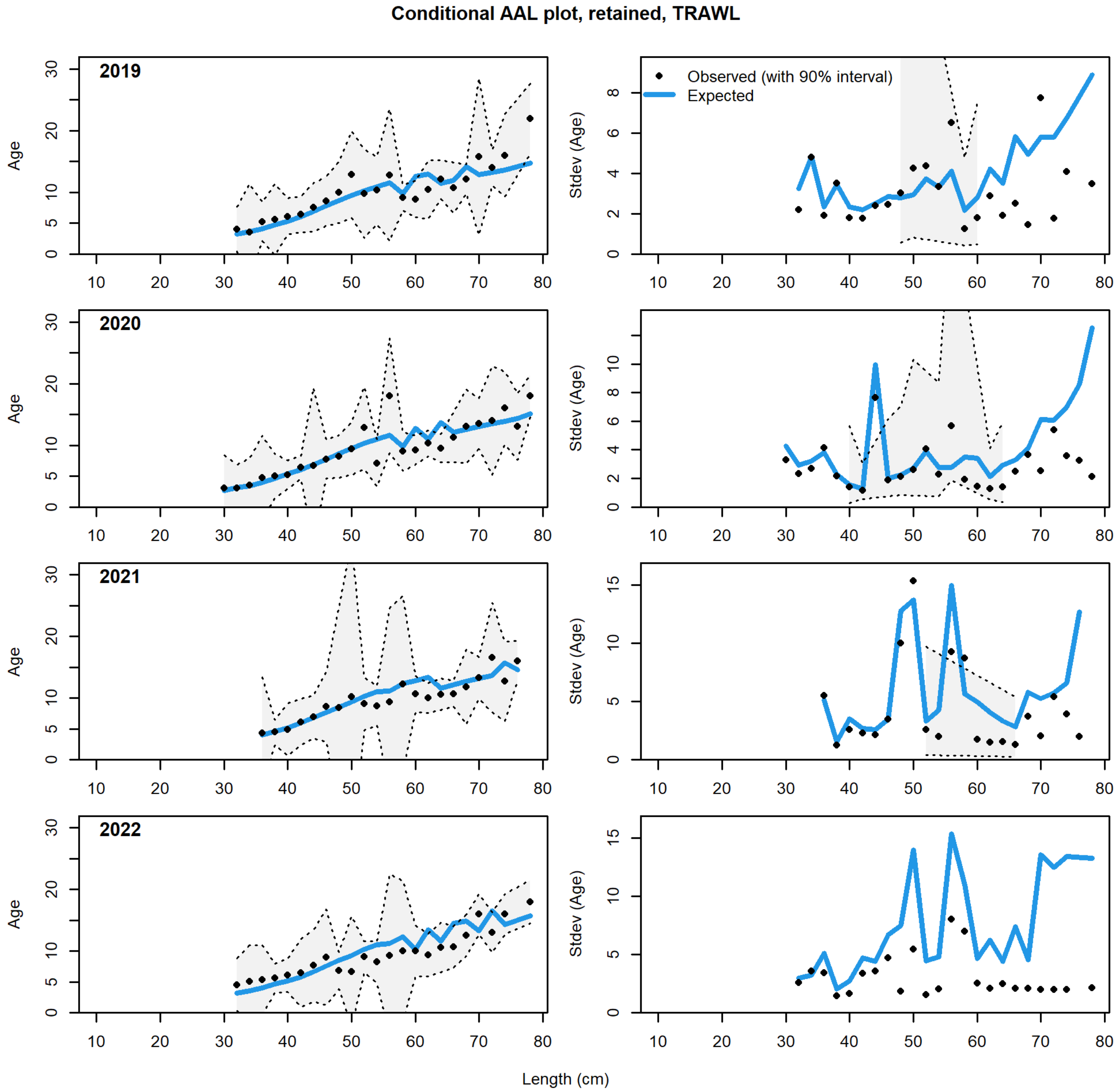
Apx Figure A.9 Pearson residuals from the annual length compositions for the 2023 base case assessment.



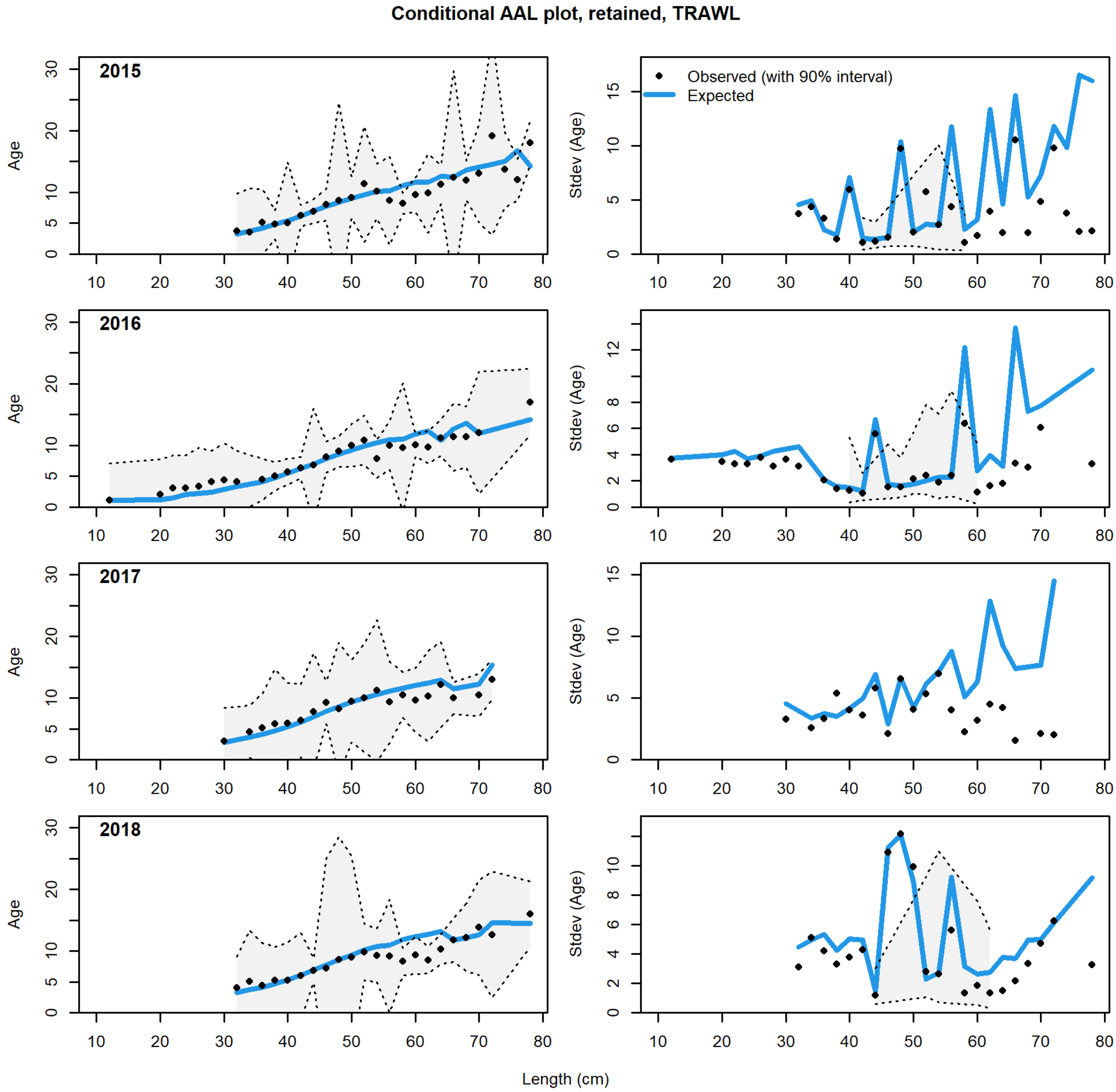
Apx Figure A.10 Fits to conditional age at length data: Danish seine.



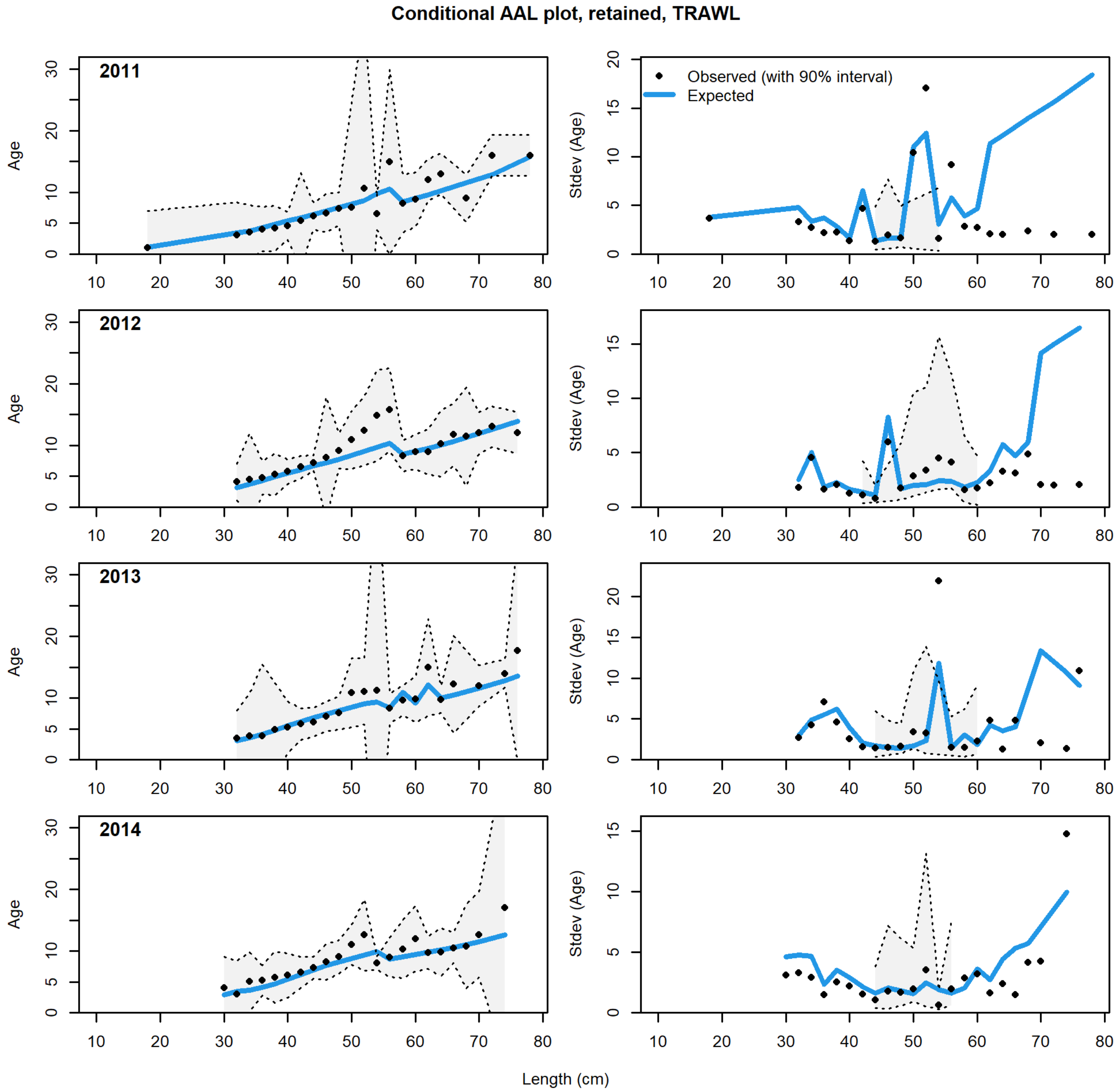
Apx Figure A.11 Fits to conditional age at length data: FIS.

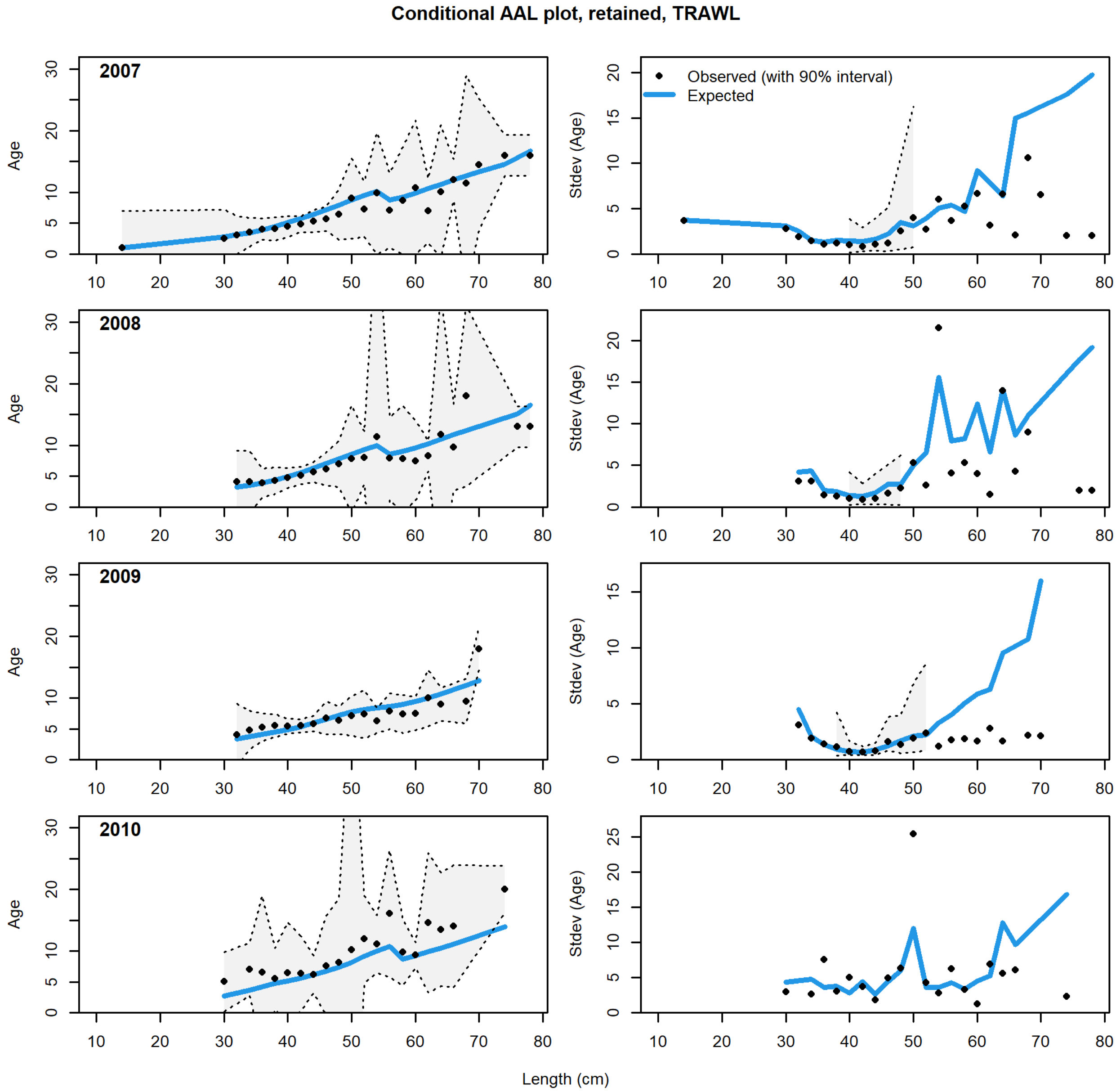


Apx Figure A.12 Fits to conditional age at length data: Trawl.



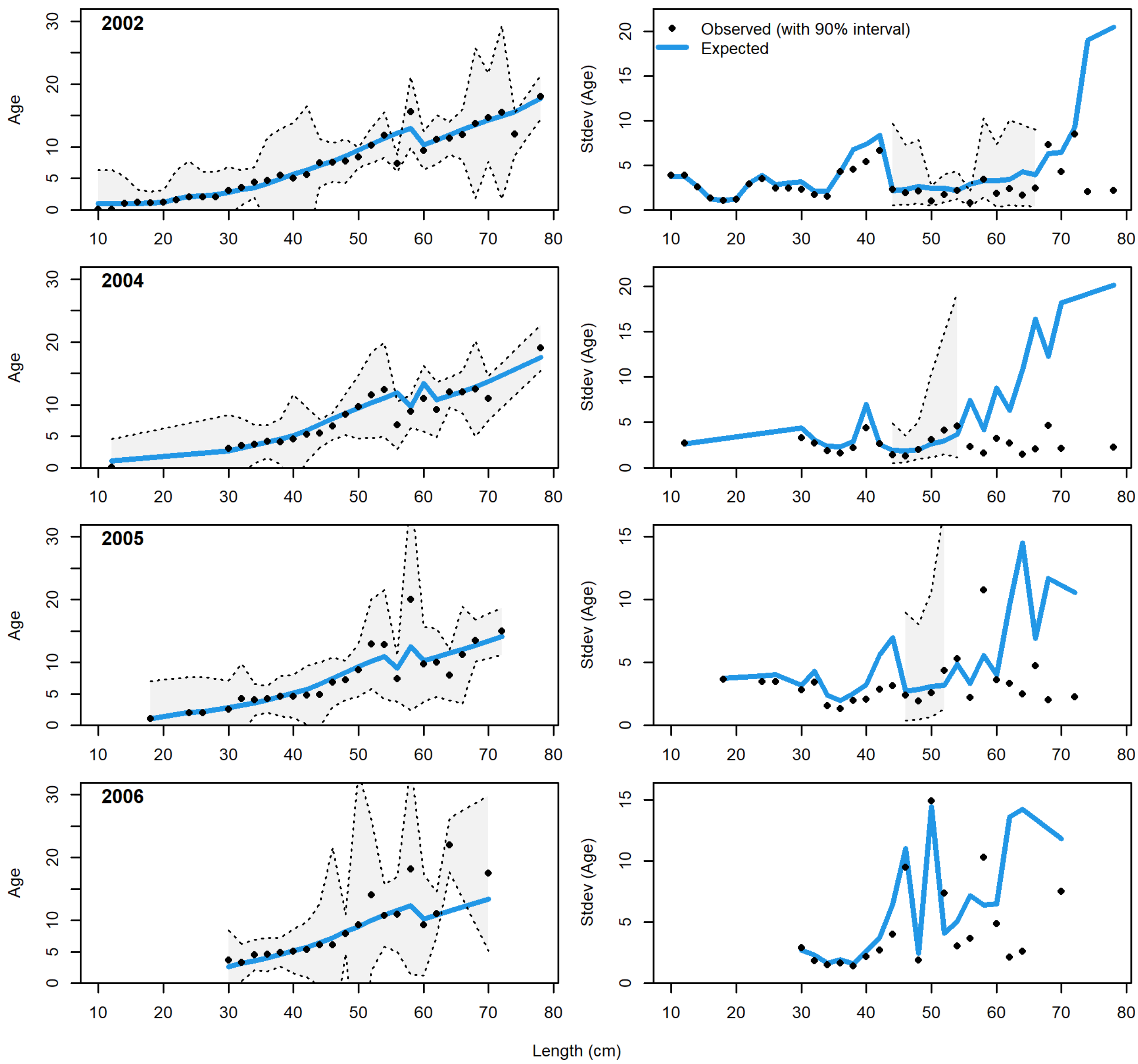
Conditional AAL plot, retained, TRAWL
2015
2016
2017
2018
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, TRAWL
2011
2012
2013
2014
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

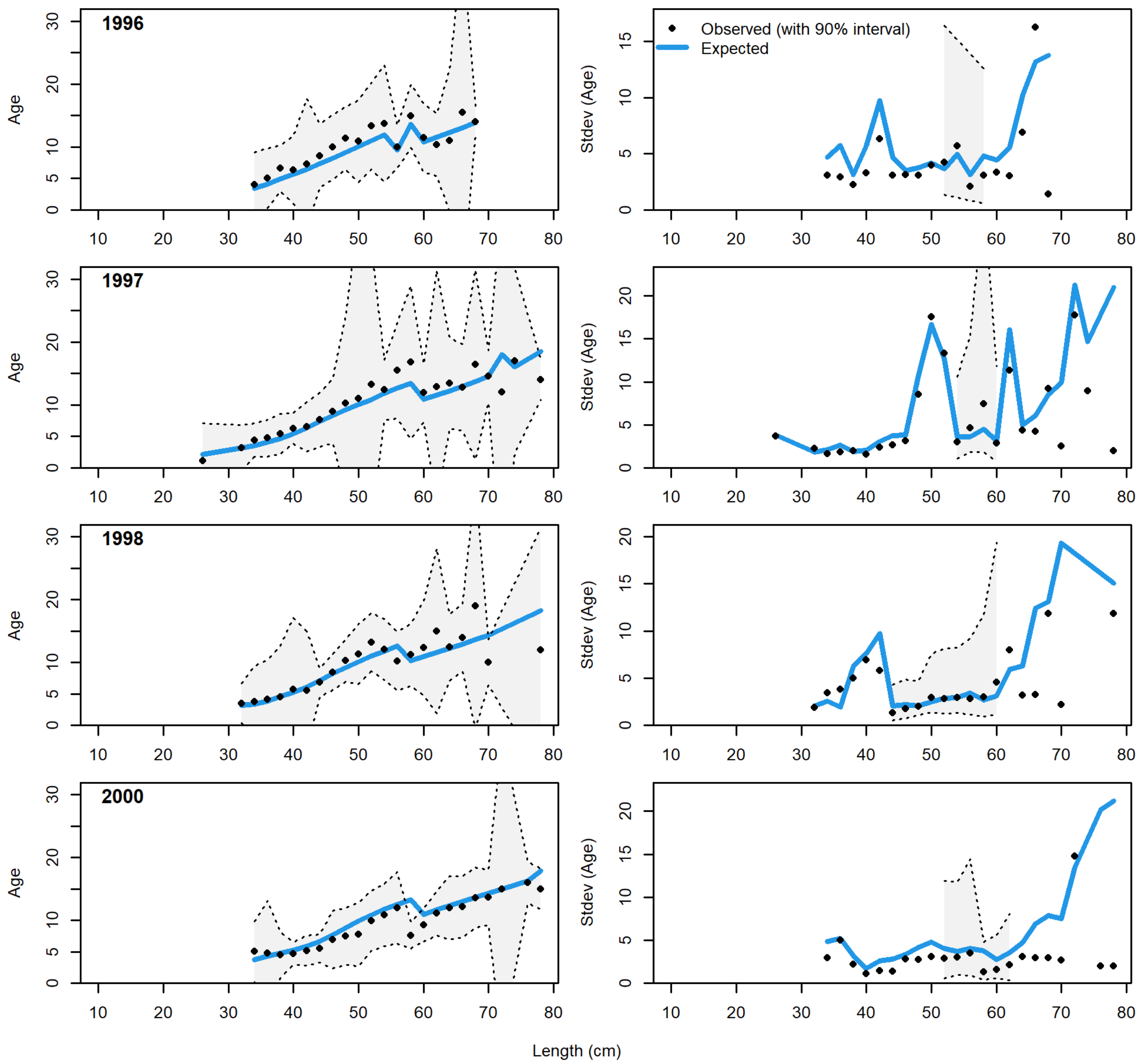


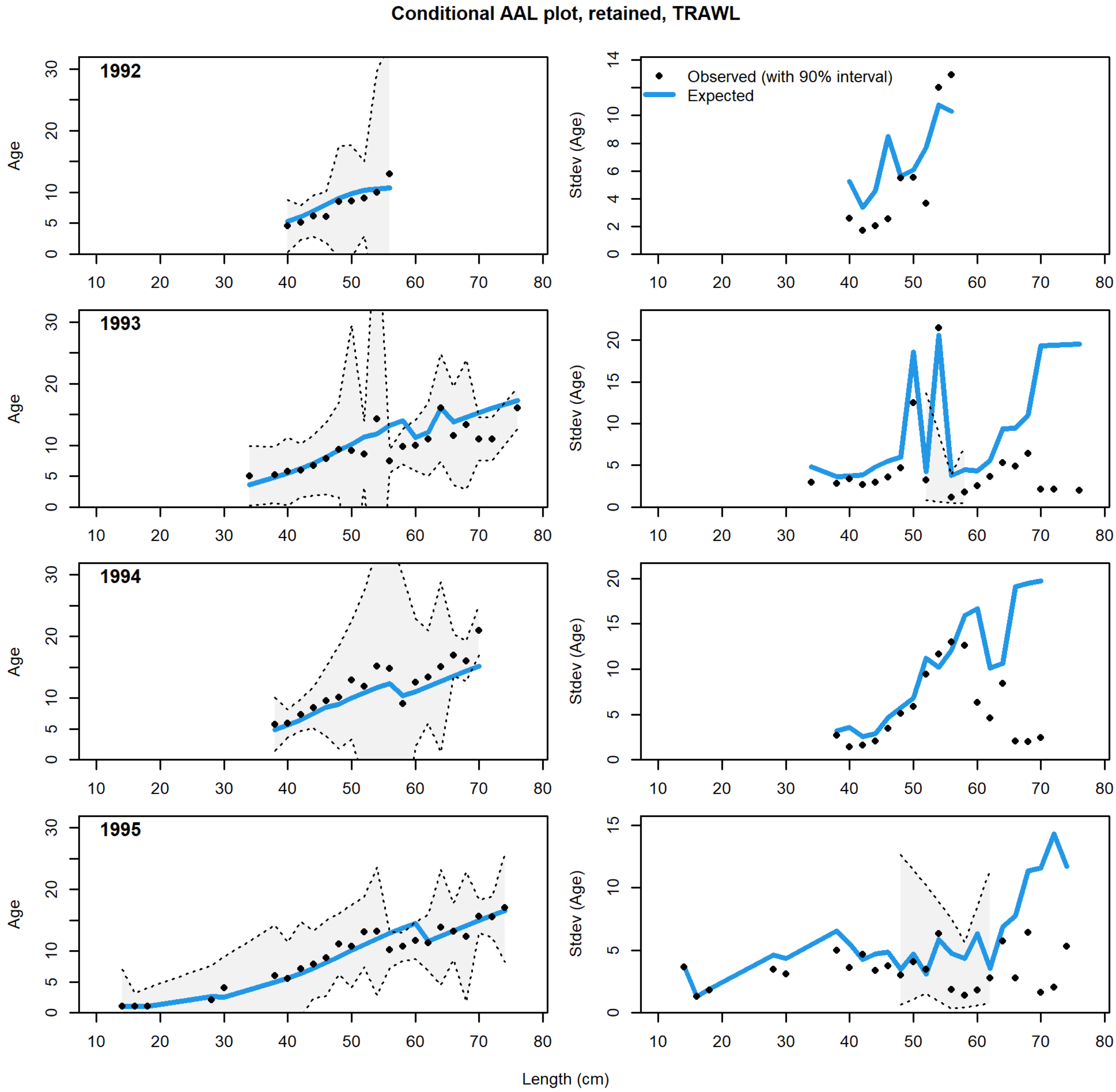
Conditional AAL plot, retained, TRAWL
2007
2008
2009
2010
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

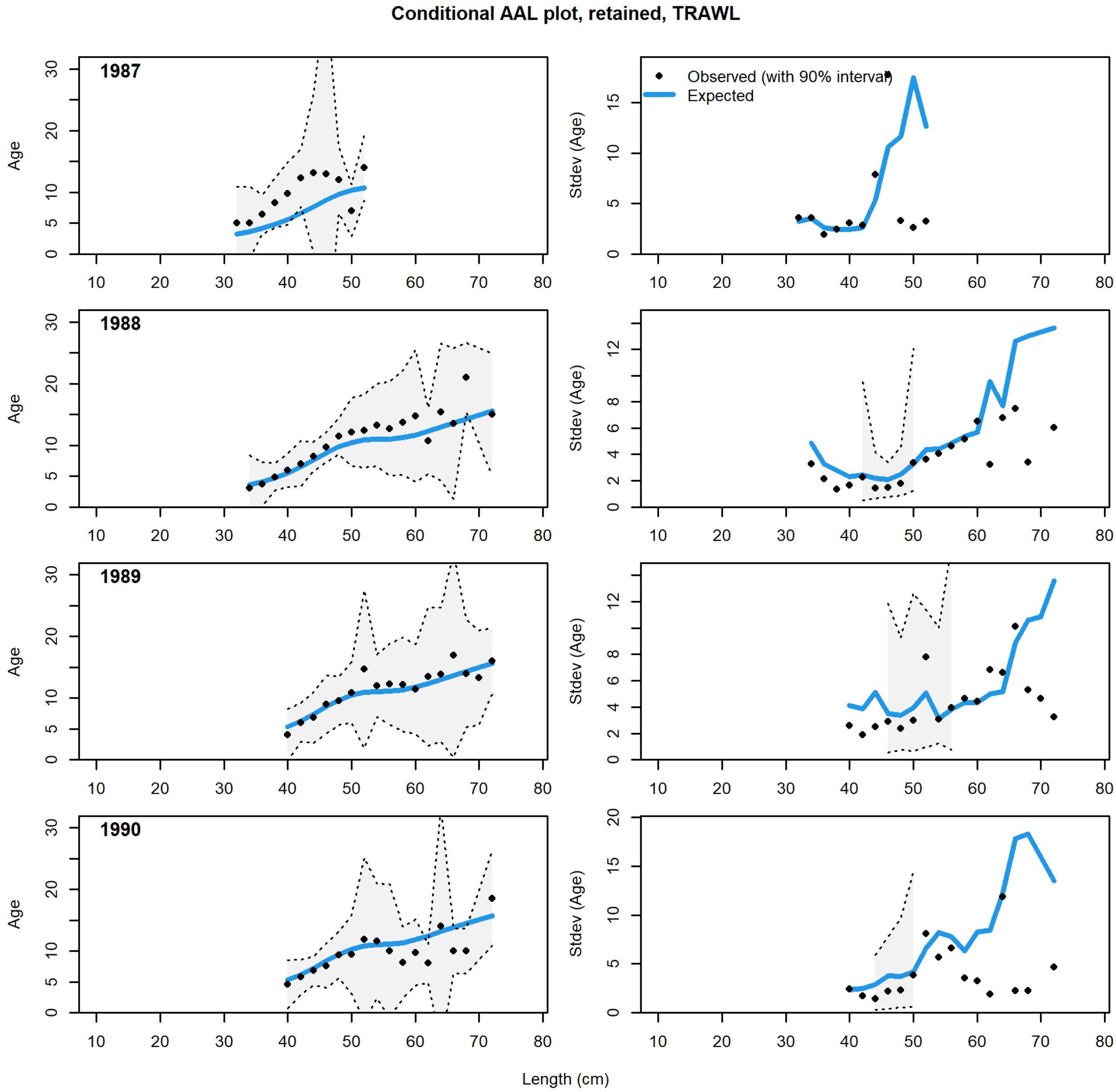
Conditional AAL plot, retained, TRAWL



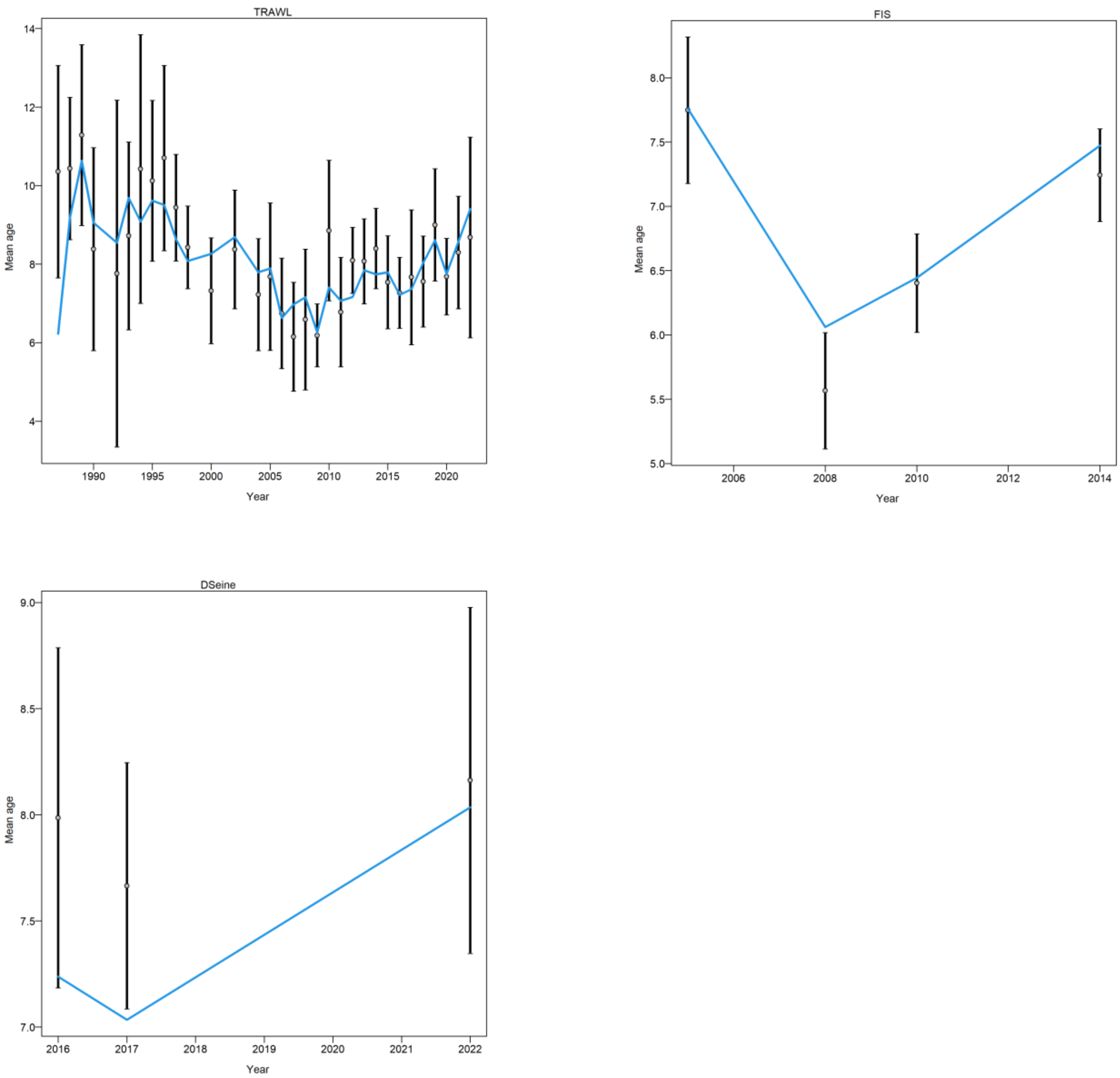
Conditional AAL plot, retained, TRAWL



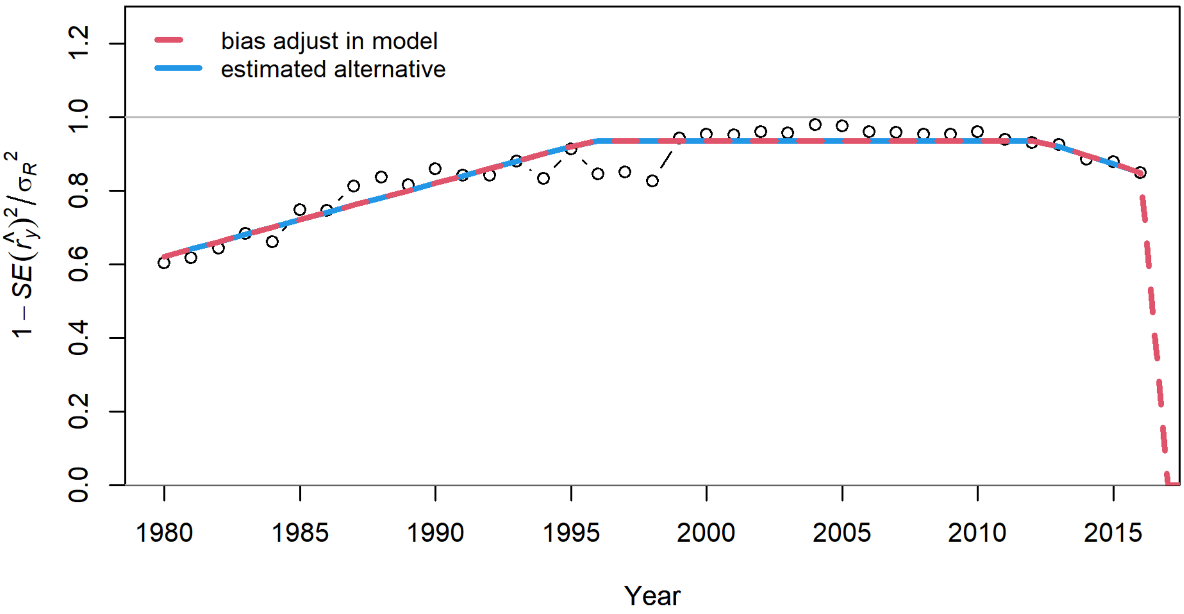

Conditional AAL plot, retained, TRAWL
1992
1993
1994
1995
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Conditional AAL plot, retained, TRAWL
1987
1988
1989
1990
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



Apx Figure A.13 Data weighting of conditional age at length data.



Apx Figure A.14 Bias ramp adjustment for Deepwater Flathead.

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