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Bight Redfish (*Centroberyx gerrardi*) stock assessment based on data to 2021-22: development of a preliminary base case

For discussion at GAB RAG, 11 October 2022, Adelaide, South Australia

Version 4.0

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Executive summary

This document presents an updated quantitative Tier 1 assessment of Bight Redfish (*Centroberyx gerradi*) for presentation at the first GAB RAG meeting in 2022. The last full assessment was presented in Sporcic *et al.* (2019). The preliminary base case has been updated by the inclusion of data to the end of financial year 2021-22, which entails an additional three years of catch, CPUE, length-composition, conditional age-at-length data and ageing error updates since the 2019 assessment, and incorporation of survey results from the March 2021 GAB Fishery Independent Survey (FIS). This document describes the process used to develop a preliminary base case for Bight Redfish through the sequential updating of recent data used by the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30.19.01).

Changes from the last stock assessment include: incorporation of South Australia states catches by financial year from 2004-05 to 2021-22 (previous assessments have used catches by calendar year) and using an updated tuning method.

Bight Redfish catches peaked at 1,008 t in 2006 and subsequently declined to less than 664 t from 2008 onwards, with further declines to less than 350 t since 2010. Since 2011 catches have remained relatively stable at between 350 t and 188 t and have been substantially lower than the agreed total allowable catch (TAC).

Results of the preliminary base case show poor fits to the CPUE and FIS abundance series, but reasonable fits to length and conditional age-at-length data. The preliminary base case assessment has estimated a continuation of above average recent recruitment, as noted in the last 3 assessments (Klaer 2011, Haddon 2015 and Sporcic et al. 2019) with the last 10 years of estimated recruitment deviations all above average. The preliminary base case assessment estimates that the projected 2023-24 female spawning stock biomass will be 67% of unfished female spawning stock (B_0), compared to 64% at the start of 2018-2019 from the 2019 assessment (Sporcic et al. 2019).

1 Introduction

1.1. The fishery and 2021-22 Bight Redfish preliminary base case

Bight Redfish (*Centroberyx gerradi*) is a demersal fish endemic to continental shelf and upper slope waters of southern Australia between ~31° S on the west coast and ~151° E on the south coast in depths from 10 to 500 m (Roberts et al. 2008). Bight Redfish is one of the most abundant and important commercial line and recreational demersal fish species on the south coast of Western Australia (WA) and further east in the Great Australian Bight (GAB), where it is exploited by the Commonwealth-managed GAB Trawl Fishery (Moore et al. 2014, Coulson et al., 2019, Norriss et al., 2020).

This species is long-lived, with a maximum age of 84 years, grows slowly, matures at a relatively old age and aggregates during spawning, which makes it vulnerable to overfishing (Coulson et al. 2019, Norriss et al. 2020).

There is considerable uncertainty of the biological stock structure of Bight Redfish. Limited analysis indicates genetic homogeneity between WA and the GAB, but some separation has been observed, based on otolith chemistry between southwest WA and the GAB (Norriss et al. 2016). More recently, Platell et al. (2022) suggest the potential for a subtle separation of four species of *Centroberyx* and two of *Beryx* from the WA and GAB, based on distributions of different species, depth and dietary compositions in both areas. Although this study shows some differences between the four species, it is not enough evidence to specify the biological stock structure of Bight Redfish. To date there has been no conclusive studies investigating the stock structure of Bight Redfish (i.e. otolith shape analysis, stable isotopes, genetic, parasite indicators or size structure) between southwest WA and the GAB.

Therefore, a single biological stock is assumed for assessment and management purposes of Bight Redfish which includes catches from the Commonwealth and South Australia, but excludes Western Australia catches.

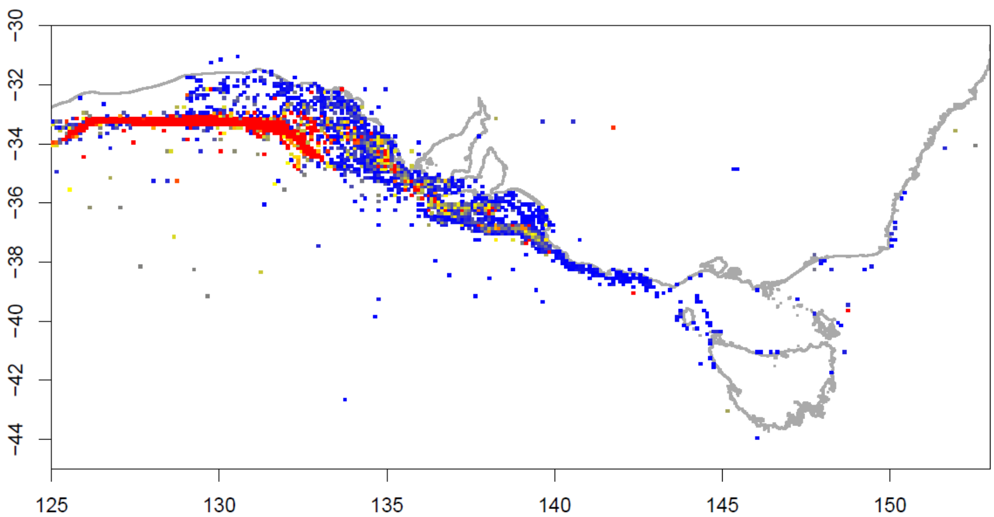

Figure 1. Bight Redfish distribution based on logbook data, colours indicate relative tonnage caught (red=high catches, blue=low catches, Thomson 2019).

The 2022 preliminary base case assessment of Bight Redfish uses an age- and size-structured model implemented in the generalised stock assessment software package, Stock Synthesis (*SS*) (Version 3.30.19.01, 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, parameterized in terms of the steepness (h) of the stock-recruitment function, 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 of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot et al. 2022).

The preliminary base case model includes the following key features:

A single region, single stock model is considered with one fleet in GAB zone (trawl). Selectivity patterns assumed to be length-specific and logistic. The parameters of the selectivity function are estimated within the assessment.

While input data are sex-specific for conditional age at length data, the base case model fits one growth curve across both sexes. Separate growth curves by sex should be considered in future models.

The initial and final years are 1960-61 and 2021-22 respectively.

The CVs of the CPUE indices were initially set at the value equal to the standard error from loess fit (0.107; Sporcic (2022)), before being re-tuned to the model-estimated standard error within *SS*.

The rate of natural mortality, M, is estimated within the assessment and is assumed to be time invariant, constant with age and the same for each sex.

Recruitment to the stock is assumed to follow a Beverton-Holt stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the stock recruitment steepness parameter, h. Steepness for the base case analysis is set to 0.75.

The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_{R}, is set to 0.699, consistent with previous assessments.

The population plus-group is modelled at age 64 years.

Growth is assumed to follow a von Bertalanffy length -at-age relationship, with the parameters of the growth function estimated together for females and males inside the assessment model.

The number of shots, rather than the number of fish measured were used as the initial effective sample sizes for the onboard retained and discarded length with sample sizes were capped at 200. Samples were required to have greater than 100 fish sampled annually required for inclusion in the model. For port samples, numbers of trips were used as the sampling unit, with a cap of 100 (which was not reached). The initial effective sample size is reduced because the appropriate sample size for length frequency data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured. Note that the initial effective sample size on the length composition data are reduced in the tuning process (see below).

The values assumed for some of the key parameters of the preliminary base case are shown in Table 1.

Table 1 Values for some of the parameters of the preliminary base-case model

PARAMETER	DESCRIPTION	VALUE
M_f	Natural mortality for females	estimated
M_m	Natural mortality for males	estimated
h	Steepness' of the Beverton-Holt stock-recruit curve	0.75 (Fixed)
σ_R	Recruitment variability	0.699 (Fixed)
$Ln(R_0)$	Log unfished recruitment	estimated
x	Age observation plus group	64 years
a_f	Female allometric length-weight equations	0.00013 g cm^{-1}
b_f	Female allometric length-weight equations	2.559
a_m	Male allometric length-weight equations	0.00014 g cm^{-1}
b_m	Male allometric length-weight equations	2.522
l_m	Female length at 50% maturity	25 cm

2 Bridging methodology

The previous full quantitative assessment for Bight Redfish was conducted incorporating data to the end of 2018-19 (Sporcic et al. 2019) using SS (version SS-V3.30.14.05; Methot 2018). The 2022 Preliminary base case assessment uses the current version of SS (version SS-V3.30.19.01; Methot 2022).

As a first step in the process of bridging to a new model, the 2019 model was translated from version *SS*-V3.30.14.05 (Methot 2018) to version SS-V3.30.19.01 (Methot et. al. 2022) using the same data and model structure used in the 2019 assessment. The catch series was then updated to include any amended estimates for the historical period from 1988-89 to 2018-19. Following this step, the model was re-tuned (The data sources re-weighted within the likelihood) using the most recent tuning protocols (Pacific Fishery Management Council, 2018), thus allowing the examination of changes to both assessment practices and the tuning procedure on the previous model structure. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2019 simply through changes to software, updated to data and assessment practices.

The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2021-22. These additional data included new catch, CPUE, the FIS abundance index from the March 2021 survey, length composition data, conditional age-at-length data and an updated ageing error matrix. Additional FIS data were also included: 2021 GAB-FIS abundance index and 2020 GAB-FIS length frequencies. The last year of recruitment estimation was extended to 2007 (from 2003 in Sporcic et al. 2019).

The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data potentially influenced changes in the assessment outcome was conducted, with the results outlined below.

3 Bridge 1

The 2019 Bight Redfish assessment (REB_2019_30_14_05) was converted to the most recent version of the software, version SS-V3.30.19.01 (REB_2019_30_19_01). There are no discernible differences to the stock status estimates throughout the timeseries between the two SS version updates (i.e., 3.30.14.05 and 3.30.19.01; Figure 2).

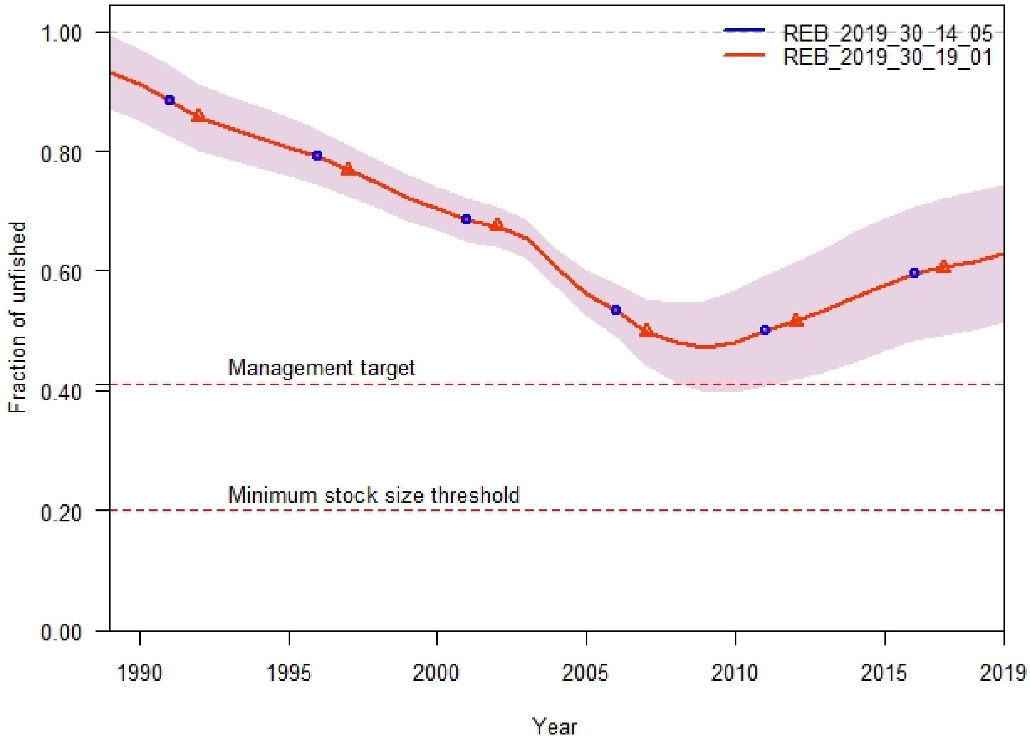

Figure 2. Comparison of the stock status time series for the 2019 assessment (REB_2019_30_14_05 – dark blue) and a model converted to SS-V3.30.19.01 (REB_2019_30_19_01 – red).

3.1 Updating catches and tuning

Revisions to the historical catches, which involved only updating the estimated 2018-19 catch with the actual 2018-19 catches, were then included (REB_2019_30_19_01_RevCatch, Figure 3). Incorporating amended catches resulted in no discernible difference to stock status estimates, tuning and revised catch (i.e., 2006-18 landed catch updated, Figure 4). The assessment was then tuned using the latest tuning protocol (REB_2019_3.30_19_01_Tuned). The initial bridging step, Bridge 1, does not incorporate any data after 2019 or any structural changes to the assessment.

When these series are plotted together, there are no discernible changes resulting from updating catches. The new tuning procedures resulted in no change to the stock status estimates or estimated recruitment deviation (Figure 3, Figure 4). Fits to the abundance indices (Figure 5, 6) show minor changes.

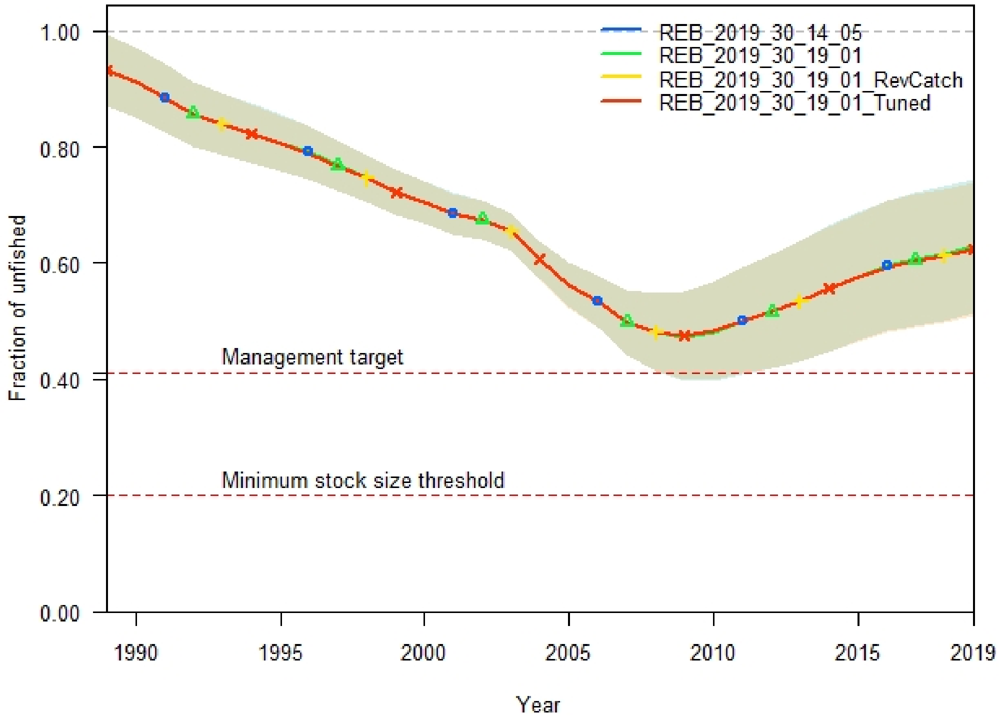

Figure 3. Comparison of the stock status time series from the 2019 assessment (REB2019_3.30.14 – dark blue), a model converted to SS-V3.30.19.01 (REB2019_3.30.19.01 – green), amended historical catch series (REB2019_3.30.19.01RevCatch – yellow) and retuning the model using the latest tuning protocols (REB2019_3.30.19.01Tuned – red).

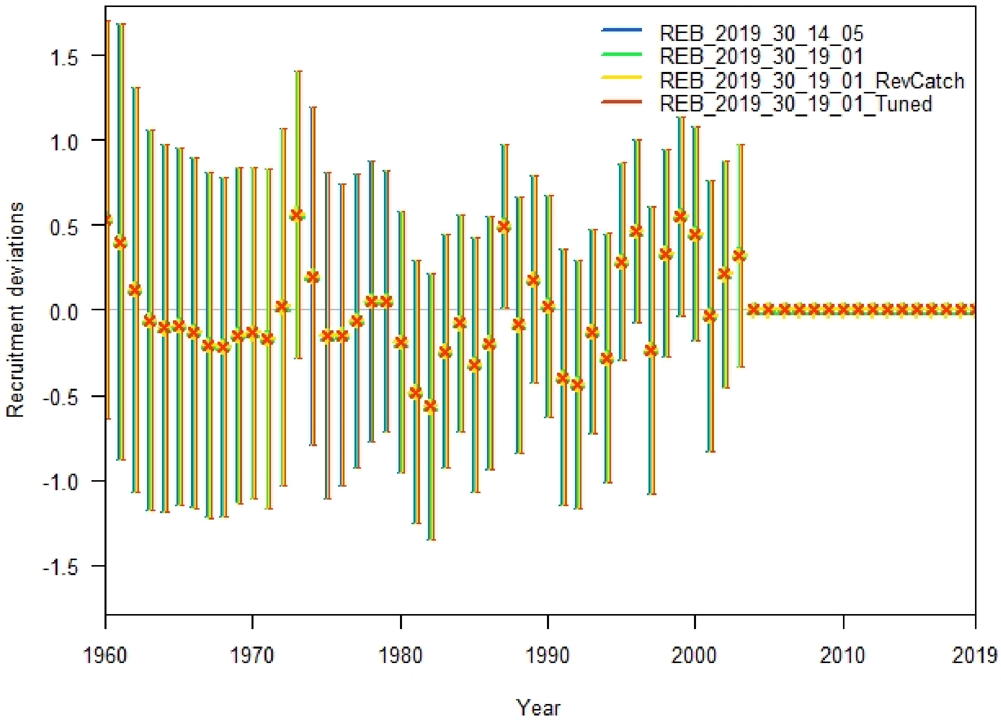

Figure 4. Comparison of the estimated recruitment deviations from the 2019 assessment.

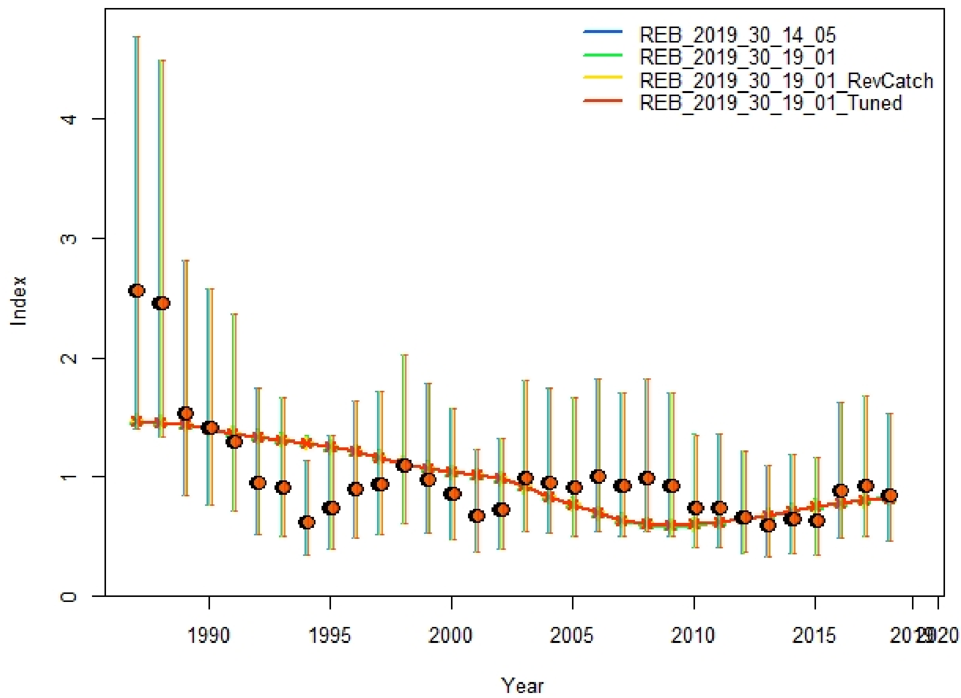

Figure 5. Comparison of the fit to the trawl CPUE index for the 2019 assessment.

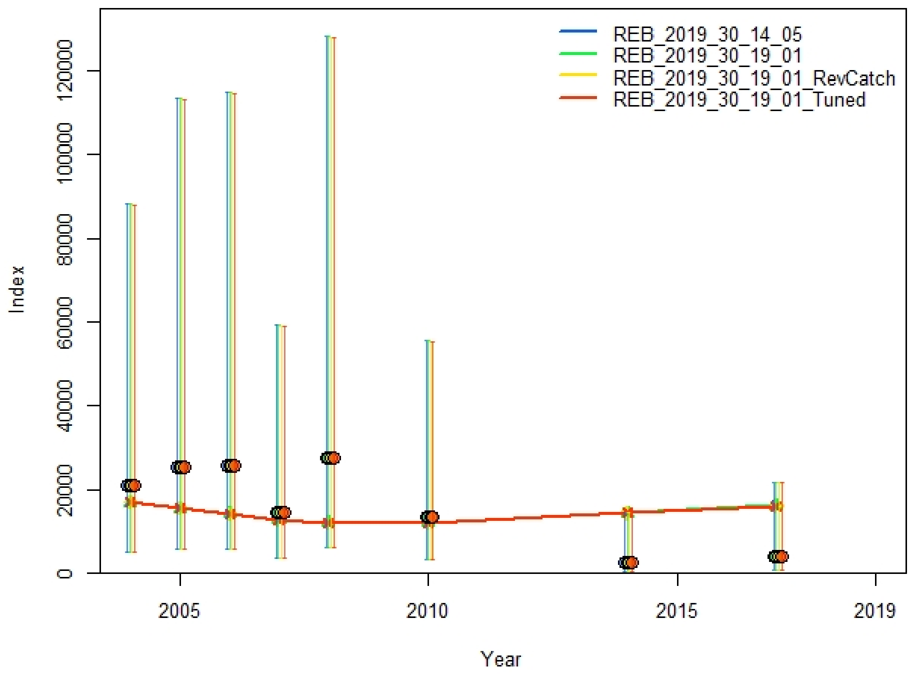

Figure 6. Comparison of the fit to the GAB-FIS abundance index for the 2019 assessment.

4 Bridge 2

4.1 Inclusion of the new data

The data inputs to the assessment come from multiple sources, including: length and conditional age-at-length data from the trawl fishery, updated standardized CPUE series (Sporcic, 2022), the annual total mass landed, and age-reading error. Data were formulated by financial year (i.e. 1 July to 30 June).

Starting from the converted 2019 base case model (REB_2019_30_19_01_Tuned) additional and updated data to 2021-22 were added sequentially to develop a preliminary base case for the 2022 assessment, these steps included:

1. Change final assessment year to 2021-22 and add catch to 2021-22 (addCatch2021).
2. Update the CPUE series to 2021-22 (from Sporcic 2022) (addCPUE2021). Note the 2021-22 CPUE only includes data to April 2022
3. Add updated GAB-FIS abundance index (Knuckey et al. 2021; addFIS2021).
4. Add updated length frequency data to 2020-21 (addLength2021).
5. Add updated age error matrix and conditional age-at-length data to 2021-22 and GAB-FIS conditional age-at-length data from 2008 (addAge2021).
6. Change the final year for which recruitments deviations are estimated from 2003 to 2007 (extendRec2007).
7. Retune using latest tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (Francis 2011; Tuned).

4.2 Available Data

An array of different data sources are available for the Bight Redfish assessment including catch (landings), standardized commercial CPUE, an index of relative abundance from the Fishery Independent Survey (FIS), length composition data from the ISMP (separated by port and on-board samples, labelled TRAWL and ISMPPort respectively), from the FIS (labelled FIS), and from crew sampling from on-board (labelled IndustLF, Figure 7). Conditional age-at-length data from the Trawl fleet and the FIS are also included.

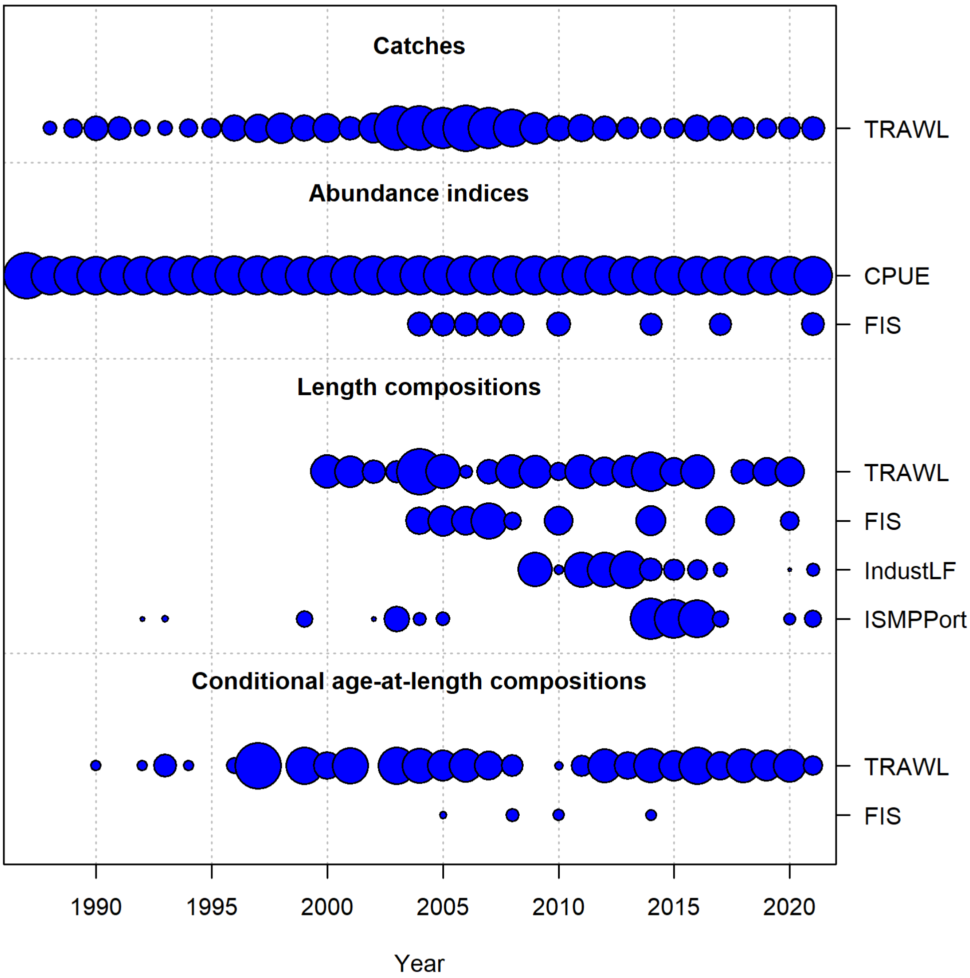

Figure 7. Data availability for the Bight Redfish assessment by type and year.

4.3 Catch and CPUE

The 2022 preliminary assessment uses the agreed catch history series from 1988-89 to 2005-06, matching that used in previous assessments (Klaer 2011, Haddon 2015, Sporcic et al. 2019). The agreed historical catches were taken from logbook estimates from 1988-89 until 2005-06 (Haddon, 2015 and Sporcic et al. 2019). This assessment updated the landed catches for 2006-07 to 2021-22 calculated from catch disposal records (CDRs; Figure 8, Table 3).

This assessment includes South Australian (SA) catches by financial year. In the 2019 assessment the SA catches were only available by calendar year and were added to the nearest Commonwealth financial year. The change to correct the calculation by financial year resulted in minor changes to the catch series (Figure 8, Table 2). The total catch by financial year to 2021-22 include the South Australian (SA) state catches from the 2022 assessment (labelled Catch 2022) and the 2019 assessment (labelled Catch 2019; Figure 8, Table 2). In addition, states catches taken by Western Australia (WA) are also displayed (labelled WA Catch 2022; Figure 8 and Table 2), however they are not included in the preliminary base case (consistent with previous assessments). The reported total landed catch for WA from 1988-1989 to 2019-20 is 535 t (Figure 9, table 2). The total catch series that includes WA catches (blue line) is slightly higher than the agreed assessment catch series between 2006-07 and 2019-20 but the two are not substantially different (Figure 8). Discards are assumed to be negligible and not included in the assessment, consistent with previous assessments.

The annual standardized CPUE used in this assessment was estimated by Sporcic (2022; Figure 9, Table 2).

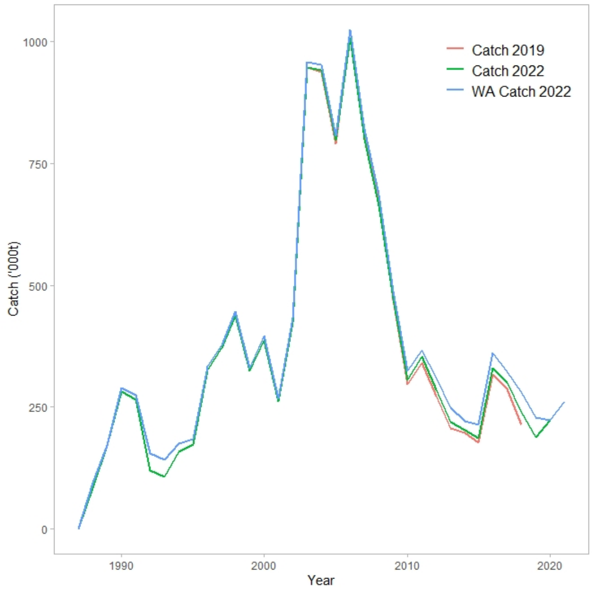

Figure 8. Total reported landed catch including South Australia states catches of Bight Redfish 1988-89 – 2021-22 from the 2019 assessment (red line), calculated for the 2022 assessment (green line), and calculated including WA catches (blue line).

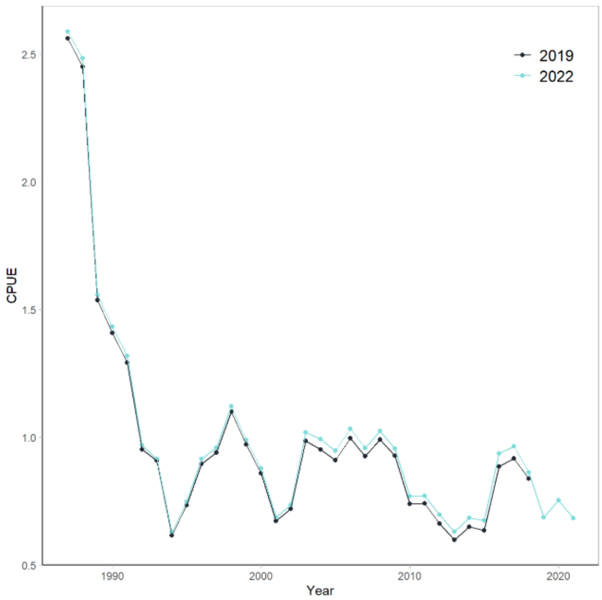

Figure 9. Comparison of the standardized CPUE for Bight Redfish from the 2019 assessment (black line) standardized CPUE used in the 2022 preliminary base case assessment (Blue line, Sporcic 2022).

Table 2. Financial year values of total catches and estimated standardized CPUE (Trawl) from 1987-88 to 2021-22. Discards are assumed to be negligible. Standardized CPUE is from Sporcic (2022). The base case catch series is presented in the 'Total catch' column.

Season	Catch (t)	SA State catch (t)	Total catch (t)	WA catch (t)	Total WA catch (t)	CPUE
1987-88						2.58
1988-89	85.65		85.65	9	94.65	2.48
1989-90	170.83		170.83	1	171.83	1.55
1990-91	281.80		281.80	8	289.80	1.43
1991-92	265.61		265.61	9	274.61	1.31
1992-93	120.69		120.69	35	155.69	0.96
1993-94	107.47		107.47	34	141.47	0.91
1994-95	157.80		157.80	17	174.80	0.62
1995-96	173.92		173.92	11	184.92	0.74
1996-97	327.17		327.17	6	333.17	0.91
1997-98	372.61		372.61	6	378.61	0.96
1998-99	437.78		437.78	8	445.78	1.12
1999-00	323.64		323.64	7	330.64	0.99
2000-01	387.87		387.87	8	395.87	0.87
2001-02	262.61		262.61	4	266.61	0.68
2002-03	424.67		424.67	8	432.67	0.73
2003-04	946.47		946.47	11	957.47	1.02
2004-05	937.45	3.49	940.95	11	951.95	0.99
2005-06	789.70	7.68	797.39	9	806.39	0.94
2006-07	1003.79	4.35	1008.14	17	1025.14	1.03
2007-08	794.87	4.88	799.75	20	819.75	0.95
2008-09	660.98	3.18	664.17	21	685.17	1.02
2009-10	469.69	3.78	473.48	15	488.48	0.95
2010-11	297.59	9.00	306.60	17	323.60	0.77
2011-12	341.48	11.77	353.25	13	366.25	0.77
2012-13	273.45	12.93	286.38	23	309.38	0.69
2013-14	207.05	12.78	219.84	30	249.84	0.63
2014-15	196.56	6.37	202.94	18	220.94	0.68
2015-16	176.95	9.31	186.26	28	214.26	0.67
2016-17	317.08	13.36	330.45	30	360.45	0.93
2017-18	288.48	12.75	301.23	21	322.23	0.96
2018-19	214.55	25.06	239.62	41	280.62	0.86
2019-20	171.54	17.34	188.88	39	227.88	0.68
2020-21	204.57	19.24	223.81		223.81	0.75
2021-22	229.38	33.11	262.49		262.49	0.68

4.4 Fishery Independent Survey abundance estimates

There are nine estimates of relative abundance from the FIS (Table 3; Knuckey et al. 2021). In the years prior to 2017-18 the survey was undertaken between February and April. The most recent survey (2020-21) was completed in one trip from the 20th to 28th of March 2021. Detailed descriptions of methods used to estimate the abundance and its coefficient of variation (CV) estimation are provided by Knuckey et al. (2021).

Table 3. FIS relative abundance estimates for Bight Redfish, including survey estimated coefficient variation

	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2014/2015	2017/2018	2021/2022
Estimate	20887	25380	25713	14591	27610	13189	2573	4053	3447
CV	0.13	0.16	0.16	0.11	0.18	0.13	0.28	0.25	0.21

4.5 GAB industry length data

The GAB Industry Association (GABIA) runs a crew-collected length sampling program for Bight Redfish and Deepwater Flathead, the two Tier 1 stocks in the GAB. The crew measure the lengths from a sample of each shot that contains Bight Redfish and Deepwater Flathead. In 2019, the data from July 2010 to June 2019 was reviewed and minor corrections were made to vessel names and species codes. These corrections were presented to the November 2019 GABRAG meeting and were approved. This process also identified that the fields for sorted/unsorted, retained/discarded or graded/ungraded were mostly not being completed. An investigation of this issue in 2021 identified that there had been some measuring of graded Bight Redfish between January 2017 and June 2021. These records have been excluded from the data in the assessment, resulting in different length composition data compared with the 2019 assessment. These changes were approved by AFMA (pers. comm. Mark Grubert) and the resultant length composition data for Bight Redfish has been used in this assessment.

In addition, in 2019 AFMA made numerous changes to their observer database, affecting length data for all years, and correcting entries in most of the important fields. This has resulted in differences in the onboard and Port length distributions and samples size in this assessment compared with those in Sporcic et al (2019). The number of length samples that were provided by AFMA in 2018-19 and the number that were provided in 2021-22 are shown in Table 4.

Table 4. Number of length samples used for the 2019 (2019A) assessment and 2022 (2022A) preliminary base case.

	Trawl			GAB-FIS			Industry			ISMP Port		
Year	2019A	2022A	Difference	2019A	2022A	Difference	2019A	2022A	Difference	2019A	2022A	Difference
1992-93	-	-	-	-	-	-	-	-	-	1	-	-
1993-94	-	-	-	-	-	-	-	-	-	2	-	-
1999-00	-	-	-	-	-	-	-	-	-	11	-	-
2000-01	3441	2568	-873	-	-	-	-	-	-	-	-	-
2001-02	2618	2618	0	-	-	-	-	-	-	-	-	-
2002-03	1173	1173	0	-	-	-	-	-	-	119	100	-19
2003-04	1511	1511	0	-	-	-	-	-	-	2717	2706	-11
2004-05	3362	3362	0	1393	1456	63	-	-	-	7108	759	-6349
2005-06	2271	2257	-14	142	1962	1820	-	-	-	8	541	533
2006-07	781	404	-377	1003	1003	0	-	-	-	-	-	-
2007-08	141	678	537	2424	2424	0	-	-	-	-	-	-
2008-09	1301	1049	-252	1231	1231	0	-	-	-	-	-	-
2009-10	2089	2015	-74	-	-	-	-	-	-	-	-	-
2010-11	217	221	4	1065	1065	0	644	644	0	-	-	-
2011-12	2219	2008	-211	-	-	-	5630	10051	4421	-	-	-
2012-13	525	452	-73	-	-	-	9290	11093	1803	-	-	-
2013-14	1197	1184	-13	-	-	-	8940	9396	456	-	-	-
2014-15	1582	1512	-70	1062	1062	0	3715	3999	284	70	70	0
2015-16	1136	1108	-28	-	-	-	2264	2313	49	62	62	0
2016-17	936	936	0	-	-	-	473	3450	2977	58	58	0
2017-18	-	-	-	807	807	0	3042	1511	-1531	11	11	0
2018-19	794	794	0	-	-	-	2894	0	-2894	-	-	-
2019-20	-	442	-	-	-	-	-	-	-	-	-	-
2020-21	-	754	-	-	405	-	-	264	264	-	253	-
2021-22	-	-	-	-		-	-	808	808	-	454	-

4.6 Age Data

The age data were received from Fish Ageing Services (FAS). Several corrections have been made to the ageing data since the 2019 assessment (Josh Barrow pers. com.). The number of age samples that were provided by FAS in 2019 and the number that were provided in 2022 are shown in Table 5. Differences were mostly minor. Age data were also collected in 1990, however, previous assessments have excluded these data due to concerns that large fish were preferentially selected and therefore, sampling was not representative.

Table 5. Number of age samples used for the 2019 (2019A) assessment and 2022 (2022A) preliminary base case.

	Trawl			GAB-FIS		
Year	2019A	2022A	Difference	2019A	2022A	Difference
1991-92	-	-	-	-	-	-
1992-93	91	90	-1	-	-	-
1993-94	224	224	0	-	-	-
1994-95	47	47	0	-	-	-
1996-97	113	113	0	-	-	-
1997-98	822	927	105	-	-	-
1999-00	595	595	0	-	-	-
2000-01	330	330	0	-	-	-
2001-02	558	558	0	-	-	-
2002-03	-	-	-	-	-	-
2003-04	601	600	-1	-	-	-
2004-05	538	537	-1	-	-	-
2005-06	413	410	-3	101	101	0
2006-07	473	472	-1	-	-	-
2007-08	355	353	-2	-	-	-
2008-09	207	207	0	295	295	0
2009-10	-	-	-	-	-	-
2010-11	34	34	0	223	223	0
2011-12	201	200	-1	-	-	-
2012-13	488	488	0	-	-	-
2013-14	332	332	0	-	-	-
2014-15	490	507	17	203	203	0
2015-16	403	404	1	-	-	-
2016-17	594	593	-1	-	-	-
2017-18	354	335	-19	-	-	-
2018-19	-	496	496	-	-	-
2019-20	-	419	419	-	-	-
2020-21	-	455	455	-	-	-
2021-22	-	169	169	-	-	-

4.7 Ageing error

An estimate of the standard deviation of age reading error was calculated from multiple readings of otoliths supplied by Josh Barrow (Fish Ageing Services) using the method of Punt et al. (2008) and is provided in Table 6. The estimate was updated from that used in the 2019 assessment to include the new aging data from 2021-22 and recent corrections to the Fish Ageing Services database. Uncertainty in 2022 ageing error estimates was similar to that in the 2019 assessment (Table 6, Sporcic, 2019).

Table 6. The estimated standard deviation of normal variation (age-reding error) around age-estimates for the different age classes of Bight Redfish for the 2019 and 2022 assessments.

2019 Assessment				2022 Assessment			
Age	StDev	Age	StDev	Age	StDev	Age	StDev
0	0.04417	33	1.45761	0	0.04133	33	1.36384
1	0.04417	34	1.50178	1	0.04133	34	1.40517
2	0.08834	35	1.54595	2	0.08266	35	1.4465
3	0.13251	36	1.59012	3	0.12399	36	1.48783
4	0.17668	37	1.63429	4	0.16531	37	1.52916
5	0.22085	38	1.67846	5	0.20664	38	1.57049
6	0.26502	39	1.72263	6	0.24797	39	1.61181
7	0.30919	40	1.7668	7	0.2893	40	1.65314
8	0.35336	41	1.81097	8	0.33063	41	1.69447
9	0.39753	42	1.85514	9	0.37196	42	1.7358
10	0.4417	43	1.89931	10	0.41329	43	1.77713
11	0.48587	44	1.94348	11	0.45461	44	1.81846
12	0.53004	45	1.98765	12	0.49594	45	1.85979
13	0.57421	46	2.03182	13	0.53727	46	1.90111
14	0.61838	47	2.07599	14	0.5786	47	1.94244
15	0.66255	48	2.12016	15	0.61993	48	1.98377
16	0.70672	49	2.16433	16	0.66126	49	2.0251
17	0.75089	50	2.2085	17	0.70259	50	2.06643
18	0.79506	51	2.25267	18	0.74391	51	2.10776
19	0.83923	52	2.29684	19	0.78524	52	2.14909
20	0.8834	53	2.34101	20	0.82657	53	2.19041
21	0.92757	54	2.38518	21	0.8679	54	2.23174
22	0.97174	55	2.42935	22	0.90923	55	2.27307
23	1.01591	56	2.47352	23	0.95056	56	2.3144
24	1.06008	57	2.51769	24	0.99189	57	2.35573
25	1.10425	58	2.56186	25	1.03321	58	2.39706
26	1.14842	59	2.60603	26	1.07454	59	2.43839
27	1.19259	60	2.6502	27	1.11587	60	2.47971
28	1.23676	61	2.69437	28	1.1572	61	2.52104
29	1.28093	62	2.73854	29	1.19853	62	2.56237
30	1.3251	63	2.78271	30	1.23986	63	2.6037
31	1.36927	64	2.82688	31	1.28119	64	2.64503
32	1.41344			32	1.32251		

4.8 Recruitment deviations

Standard practice for Bridge 2 is to include the same number of recruitment deviations as the number of additional years of data that are included in the assessment update. In this case, as there was an additional three years of data, it is standard practice to include an additional three recruitment deviations. However, in some circumstances there may not be sufficient information in the newly incorporated data to inform estimation of all of the extra recruitment deviations, whereas at other times there may be additional information available to inform estimation of additional recruitment deviations.

We undertook a sensitivity to estimate extra recruitment deviations in addition to the bridging steps undertaken above. Recruitment strengths that have been estimated from very few observations are often revised downwards in subsequent assessments once more observations become available. When choosing the number of recruitment deviations to include it is best practice to ensure that they are well estimated and have a similar variance to the other most recent estimates. This is demonstrated in Figure 10, where extending recruitment deviations to 2006 and 2007 resulted in well estimated values, however when extending to 2008 and 2009 there is an increase in variance. The large variance associated with 2008 (+5 years) and 2009 (+6 years) recruitment deviation suggest there is insufficient data in the assessment to inform reliable estimation of these parameters (Figure 10). Therefore, recruitment deviations have only been extended to 2007 for the 2022 preliminary base case.

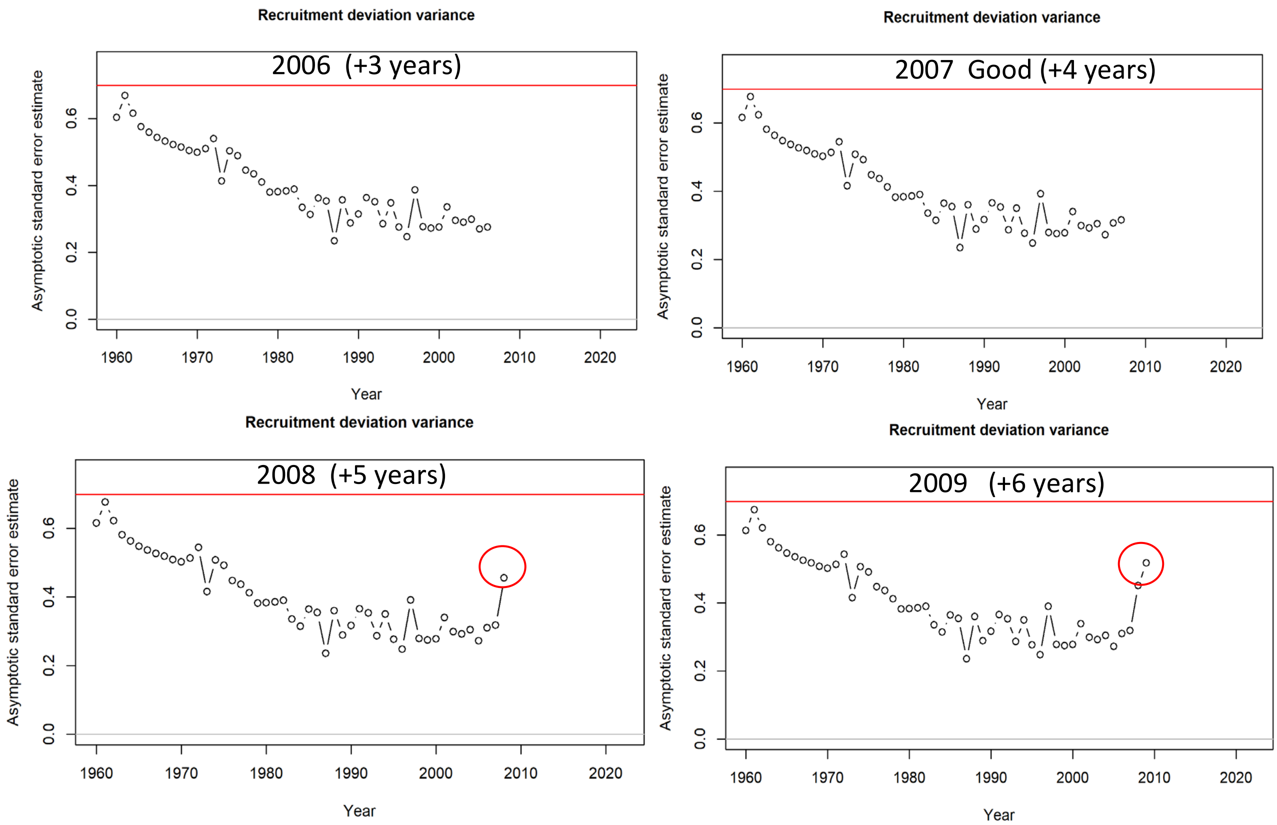

Figure 10. Estimated variance of each recruitment deviation in the model with recruitment desviation extended from 2006 to 2009.

5 Preliminary 2022 base-case assessment

5.1 Results

Inclusion of the new data resulted in a series of changes to the model results. The addition of catch data made no difference to the estimated spawning biomass (Figure 11). The addition of updated CPUE and FIS series resulted in decreased spawning biomass and stock status (Figures 11, 12). The addition of updated length data slightly reduced spawning biomass from 1960 to 2020 (Figures 11, 12). The addition of the 2021 conditional age at length data resulted in lower spawning biomass, stock status and recruitment estimates at the start of the model (1988-1990) and at the end of the model (2009 -2021) (Figures 11, 12, 13).

Peaks in estimated recruitment are generally revised downwards between 1980 and 2000, as more data are added (Figure 14). By contrast, as more data are added, there is an increase to the 2007 estimated recruitment, with a slight decrease at the final step (re-tuning the model; Figure 14). Extending recruitment deviation and then tuning resulted in slight downward revision throughout the series (Figure 14).

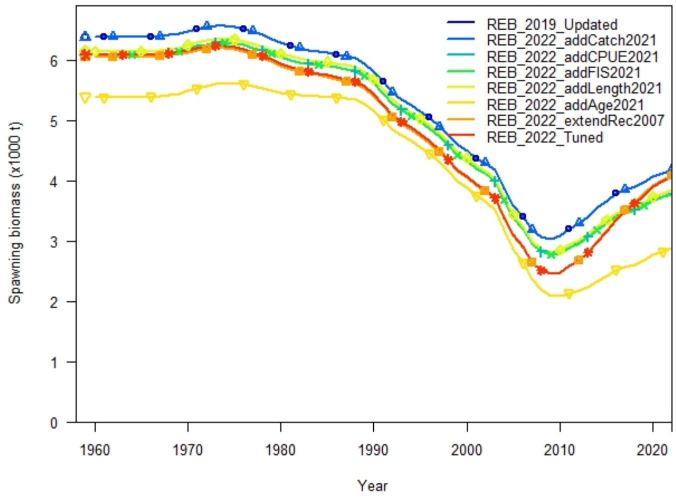

Figure 11. Comparison of the absolute spawning biomass for the updated 2019 assessment converted to SS-V3.30.19.01 (REB_2029_Updated- blue) with various bridging models leading to the 2022 preliminary base case model (REB_2022_Tuned - red).

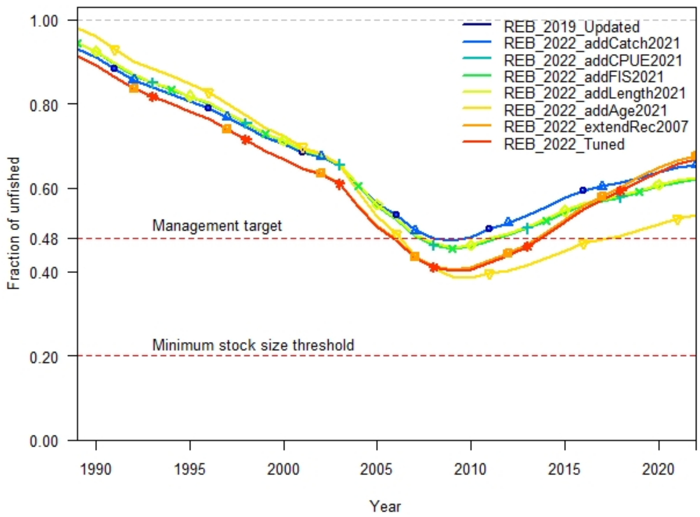

Figure 12. Comparison of the fit the relative biomass for the updated 2019 assessment model converted to SS-V3.30.19.01 (REB_2019_Updated- blue) with various bridging models leading to the 2022 preliminary base case model (REB_2022_Tuned)

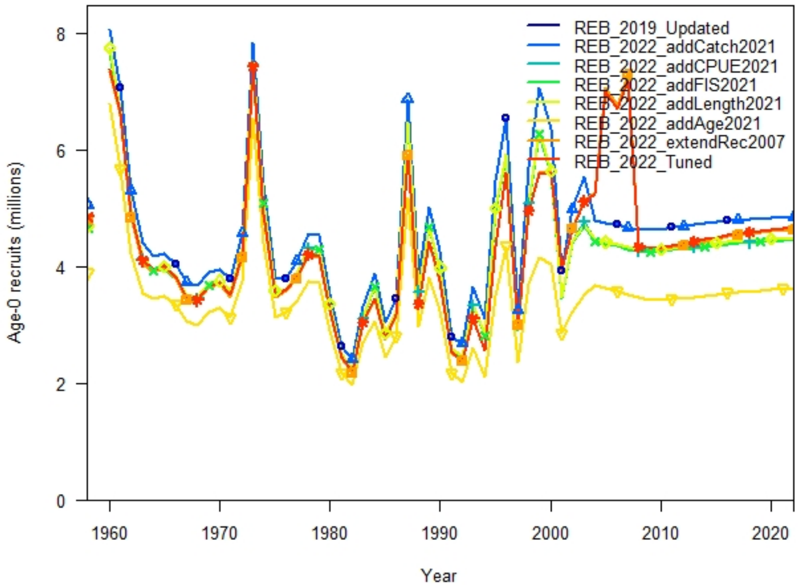

Figure 13. Comparison of the estimated recruitments for the updated 2019 assessment model converted to SS-V3.30.19 (REB_2019_Updated – dark blue) with various bridging models leading to the 2022 preliminary base case model (REB_2019_Tuned – red).

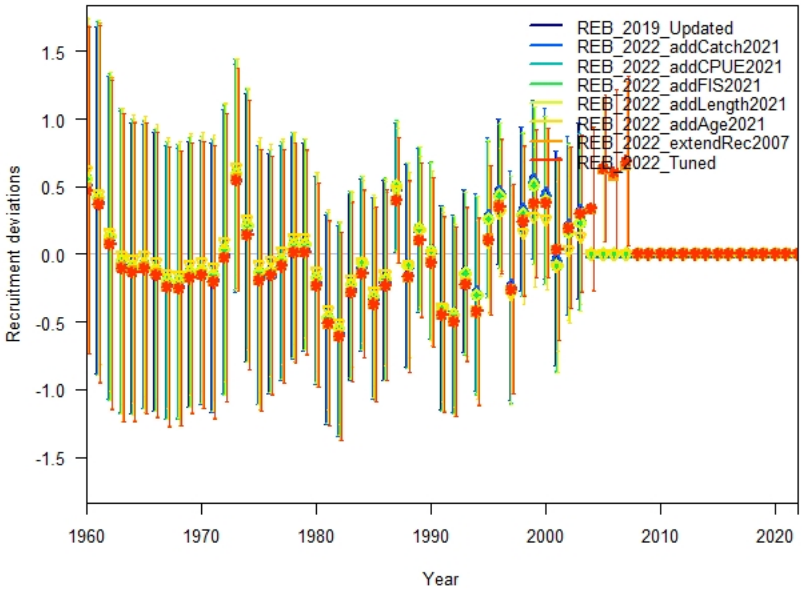

Figure 14. Comparison of the estimated recruitments deviations for the updated 2019 assessment model converted to SS-V3.30.19 (REB_2019_Updated – dark blue) with various bridging models leading to the 2022 preliminary base case (REB_2019_Tuned – red).

The impact of inclusion of the new data on fits to trawl fleet CPUE series and GAB-FIS indices were generally small (Figures 15, 16). In both series, fits to these data are poor. This is due to the biology and life span of this species making it difficult for the model to fit to the short-term variability evident in the abundance series. This lack of fit to the CPUE and FIS (Figures 15, 16) suggests that CPUE and FIS may be showing short term changes that do not solely reflect changes in population abundance.

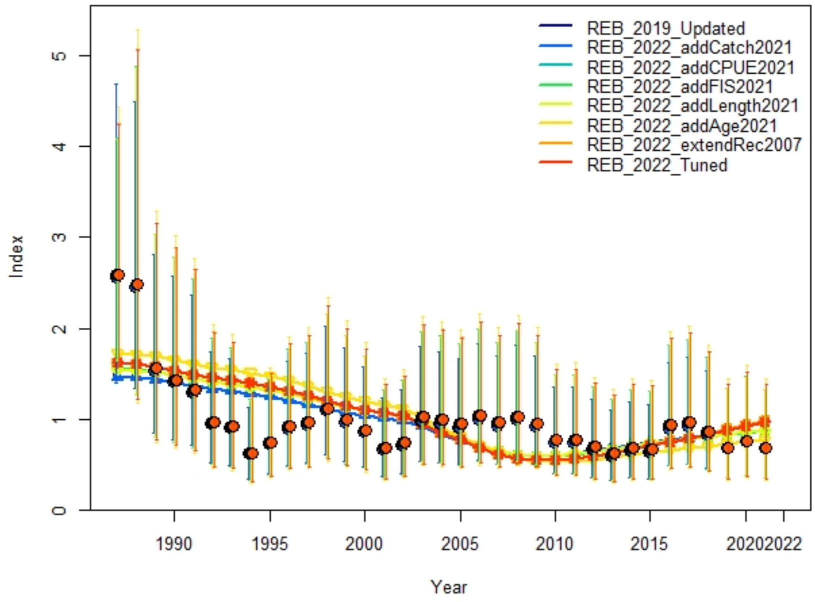

Figure 15. Comparison of the fit to the trawl CPUE index for the updated 2019 assessment model converted to SS-V3.30.19 (REB_2019_Updated – dark blue) with various bridging models leading to the 2022 preliminary base case (REB_2022_Tuned – red).

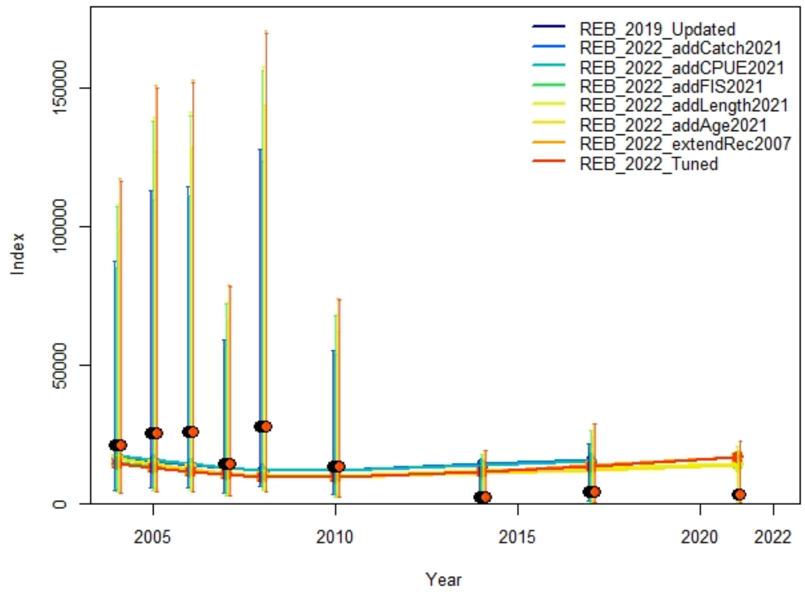

Figure 16. Comparison of the fit to the FIS abundance index for the updated 2019 assessment model converted to SS-V3.30.19 (REB_2019_Updated – dark blue) with various bridging models leading to the 2022 preliminary base case (REB_2022_Tuned – red).

6 Fits to data – 2022 Preliminary base case

Estimated output and fits to the preliminary base case model are presented in Figures 17-57. Most fits are comparable to those in the previous assessment (see Sporcic et al. (2019)). The preliminary base-case model converged with final gradient <1e^{-4} and positive definite Hessian. A jitter analysis was undertaken varying the starting parameter value by up to 10%. This determined that there was less than 1e^{-4} variability among the likelihood components and parameters estimates from the assessment undertaken with different starting values. Overall the fits to the conditional age at length and length frequency data are good, however, the fits to the CPUE and FIS index are poor. Further diagnostics are presented in the Appendix.

The stock status at the end of 2022-23 is estimated to be approximately 0.68 B_0 (Figure 17). The estimate recruitment and recruitment deviates through the period of the fishery have not varied to any substantial extent (Figure 18, 19). Since 1998 Bight Redfish recruitment has been above average levels. The fits to the catch rate indices are poor with the predicted commercial CPUE trajectory not reflecting the inter-annual variability and instead declining gradually until 2008-09 before increasing until the end of the time series in 2021-22 (Figure 20). The FIS relative abundance index follows the same trend as the commercial CPUE in their over-lapping periods and the only way to fit the predicted FIS abundance is to estimate large CV values for each data point during the re-balancing (tuning) process (Figure 21). This lack of fit to the CPUE and FIS indices (Figures 20, 21) suggests that there is conflict between the index data and the age and length composition data such that despite trying to closely fit to the relative abundance indices the model puts more weight on the composition data, preferentially fitting these data sources, due to the inconsistencies in the relative abundance indices.

The estimated growth curve for female and male Bight Redfish is assumed to be the same (Figure 27). The estimated growth and selectivity parameters for the 2022 preliminary base case were similar to the estimated parameters of the 2019 base-case (Table 7, Sporcic et al. 2019). Fits to the length composition data are good (Figures 41-44), however, there are some years of port ISMP sampling that appear to be inconsistent (2002 and 2004 port; Figure 44). The model fits the observed conditional age at length data reasonably well for both ISMP and FIS samples (Figures 46-50).

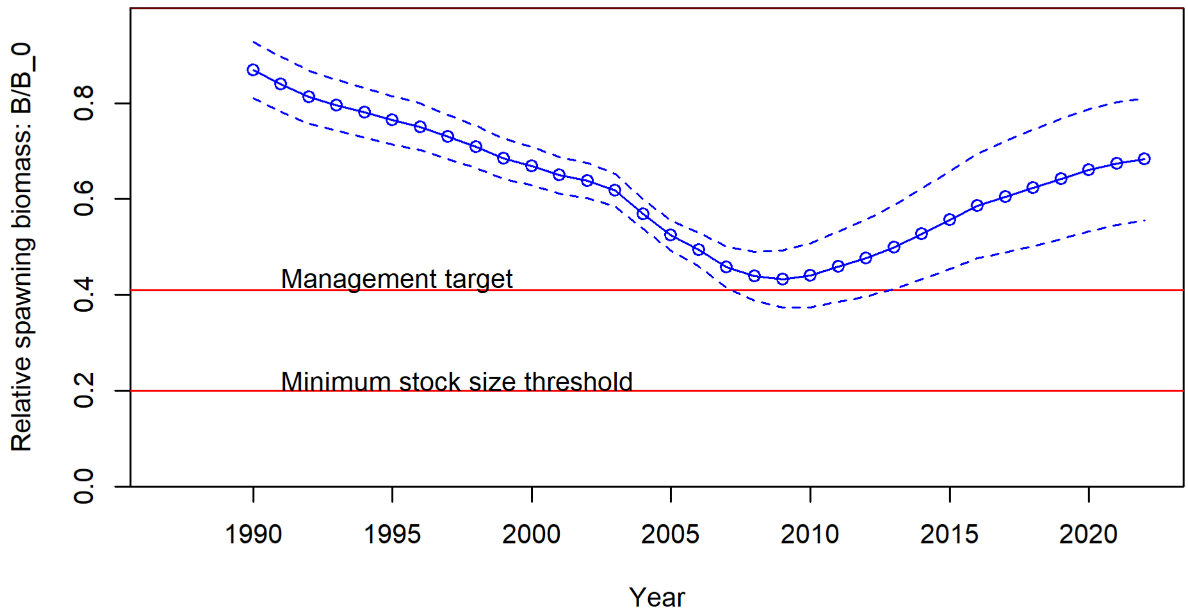

Figure 17. The estimated time-series of relative spawning biomass for the 2022 preliminary base case assessment.

Table 7. The estimated parameters for the 2022 preliminary base-case assessment and the 2019 base-case assessment with updated software and model assumptions (REB_2019_Updated).

Estimated parameters	2022 estimate	2019 estimate
M	0.1065	0.1025
$Ln(R_0)$	8.532	8.529
Recruitment deviations 1960-2007		
Growth		
k	0.080671	0.075878
L_{min}	19.6771	19.1419
L_{∞}	37.9 (Fixed)	37.9 (Fixed)
Selectivity		
Selectivity logistic inflection trawl	30.541	30.2276
Selectivity logistic width trawl	4.661	4.69167
Selectivity logistic inflection FIS	30.3	30.607
Selectivity logistic width FIS	4.749	4.92438
q CPUE catchability	0.240	0.138694
q FIS catchability	0.760354	0.603874

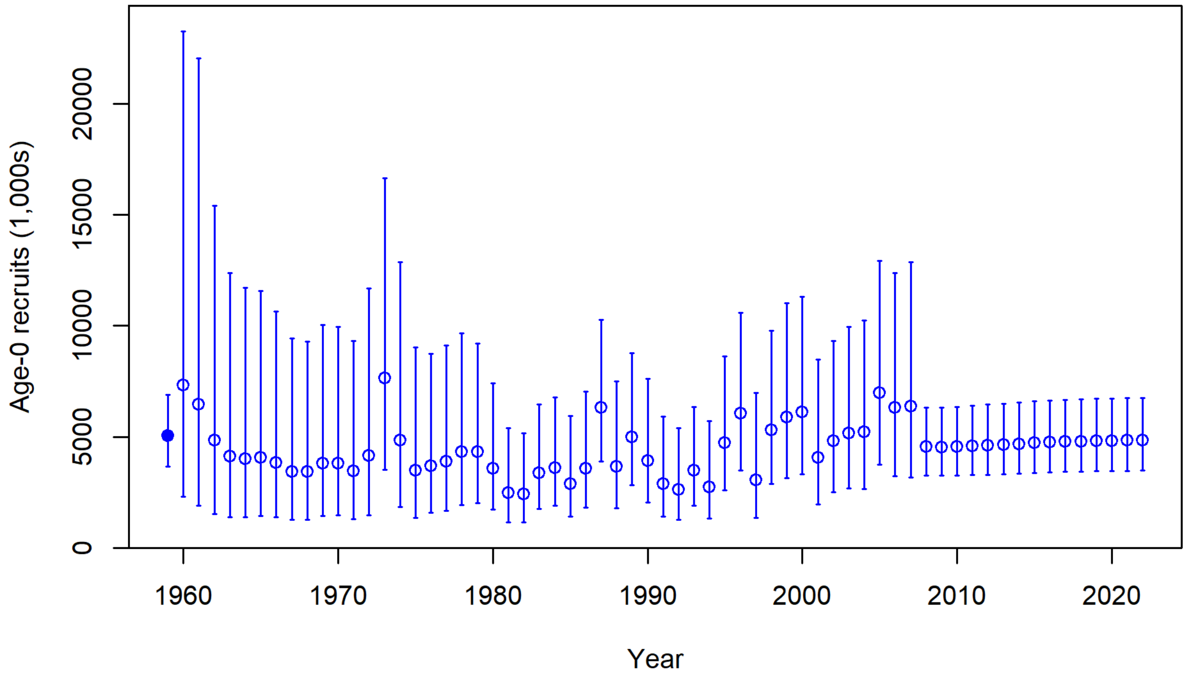

Figure 18. The estimated time-series of recruitment for the 2022 preliminary base case assessment with ~95% asymptotic intervals.

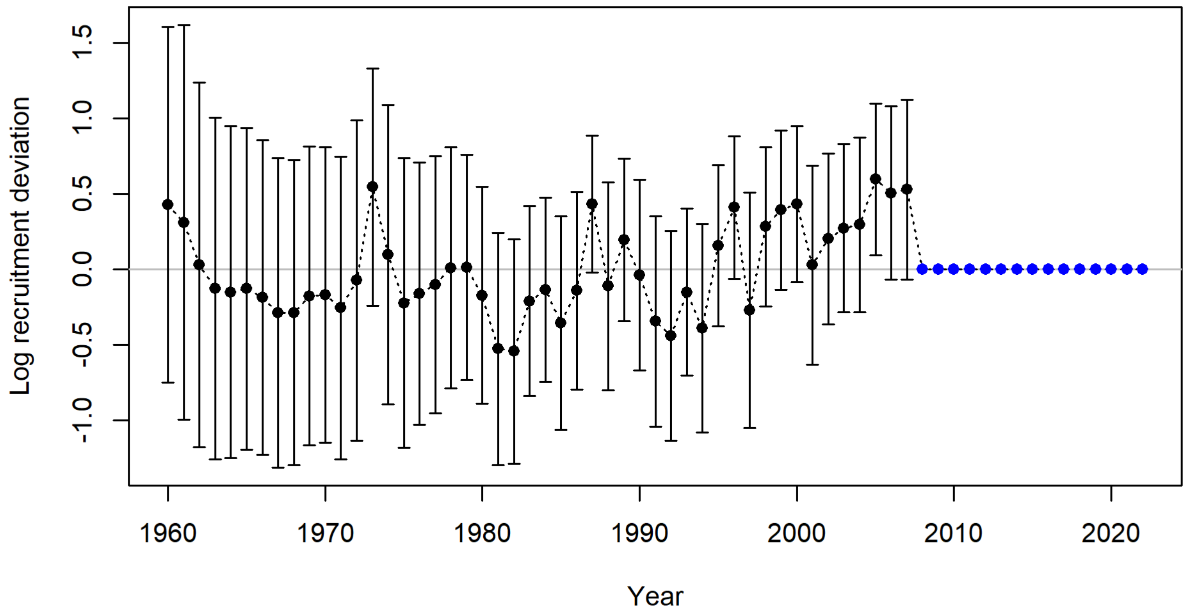

Figure 19. The estimated time-series of recruitment deviations for the 2022 preliminary base case assessment with ~95% asymptotic intervals.

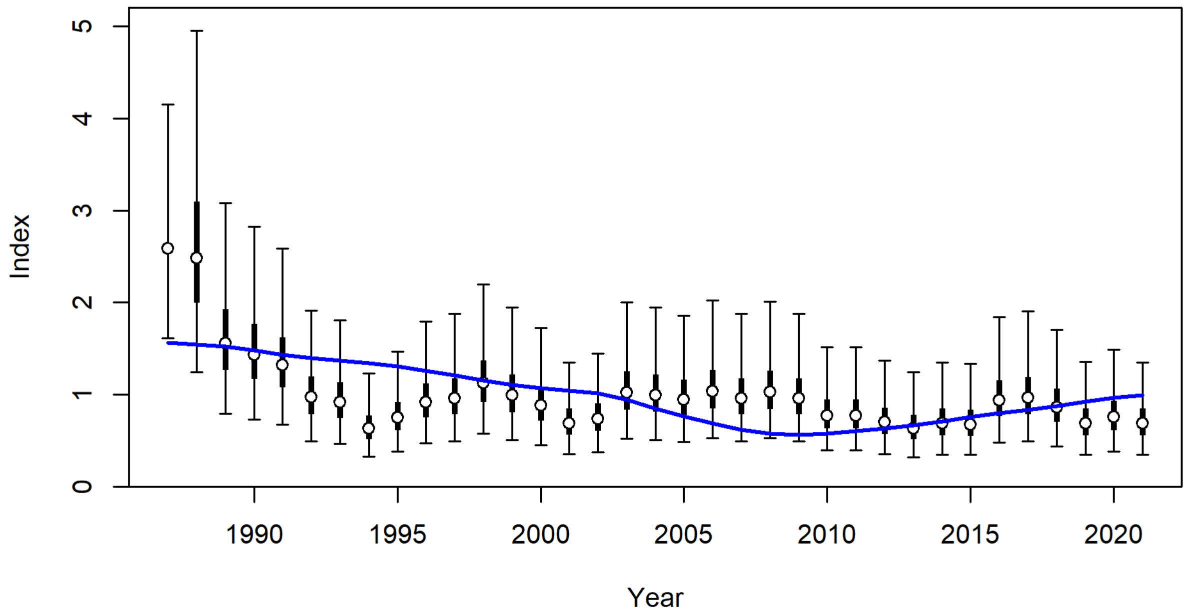

Figure 20. Fits to the trawl CPUE index for the 2022 preliminary base case assessment.

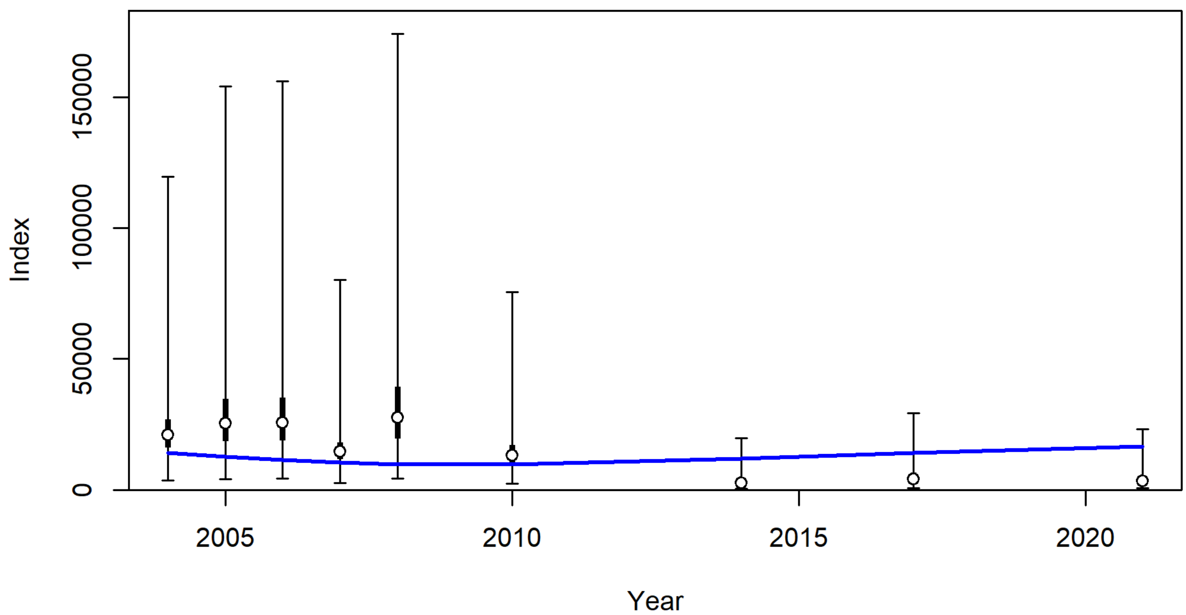

Figure 21. Fits to the FIS index for the 2022 preliminary base case assessment.

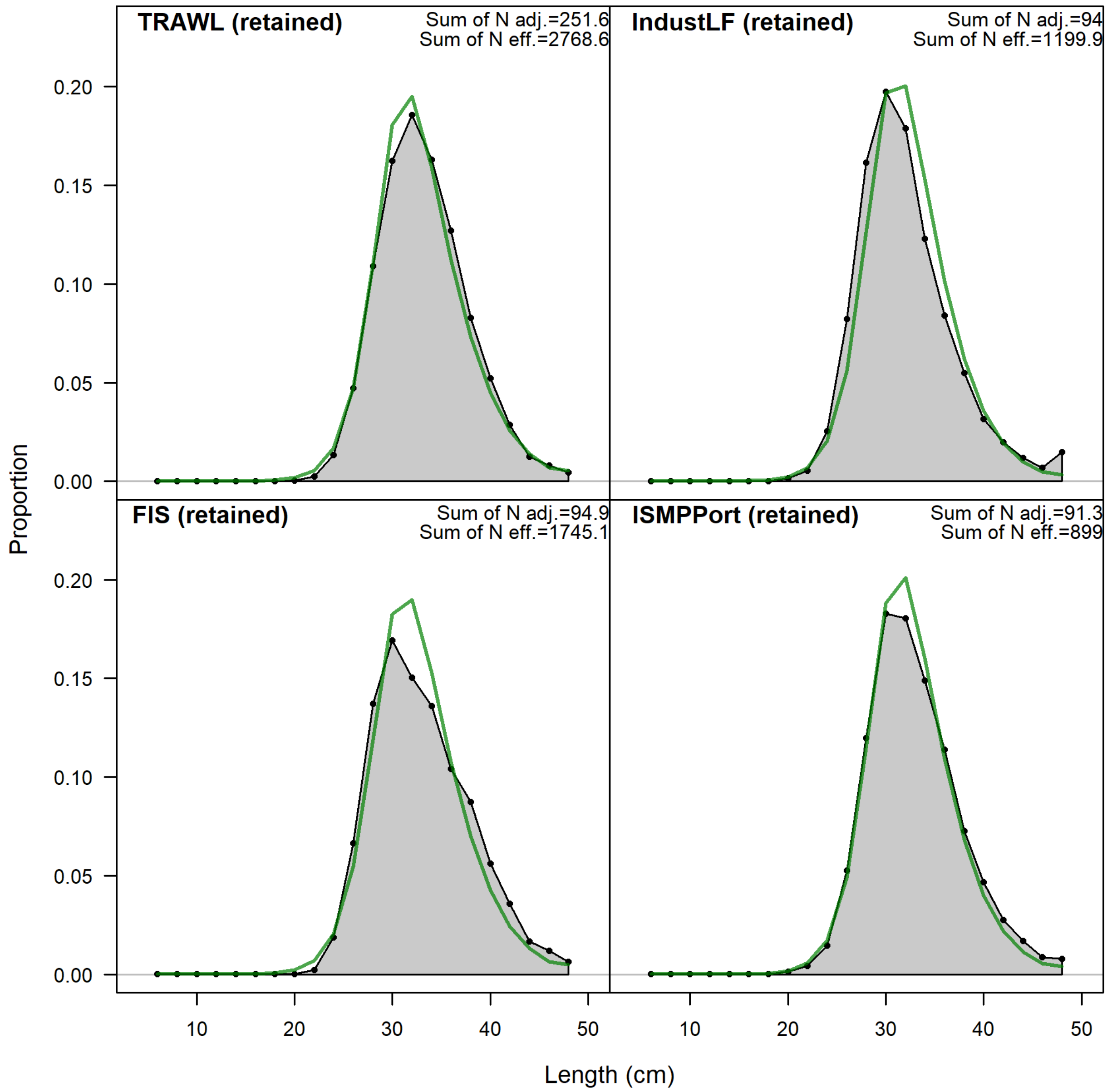

Figure 22. Fits to the aggregated length data for the 2022 preliminary base case assessment.

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 *h* 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 inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Standard parameters to consider are natural mortality (*M*) and steepness (*h*).

7.1.1 Natural mortality (*M*)

The likelihood profile for natural mortality shows that the negative log-likelihood for *M* is minimised at 0.100 yr^{-1} with 95% confidence intervals ranging between approximately 0.093 yr^{-1} and 0.106 yr^{-1} (Figure 23). This is slightly lower than the maximum likelihood estimate of M=0.1017 yr^{-1} that was obtained from the likelihood profile for *M* undertaken in the 2019 assessment (Sporcic et al. 2019). Age data appears highly informative and representative of overall profile shape, with similar minimum values (Figure 23, Table 8). The index (suggesting higher values) and length data (suggesting lower values) show some conflict (Figure 23).

The contribution of each fleet to the likelihood components are presented in Figure 24 and Table 8. Lower values of *M* in the length component of the likelihood are driven by the trawl, FIS, Industry (IndustLF) and ISMP port fleets (Figure 24, Table 8). Conditional age at length data suggests similar *M* to the total value and the low *M* estimates are driven by FIS fleet, although there is little information in this data (Figure 24, Table 8). For survey or index likelihood the high *M* estimates are driven by the CPUE index and the lower estimates of *M* are driven by FIS index, although again the there is little information in the FIS index (Figure 24).

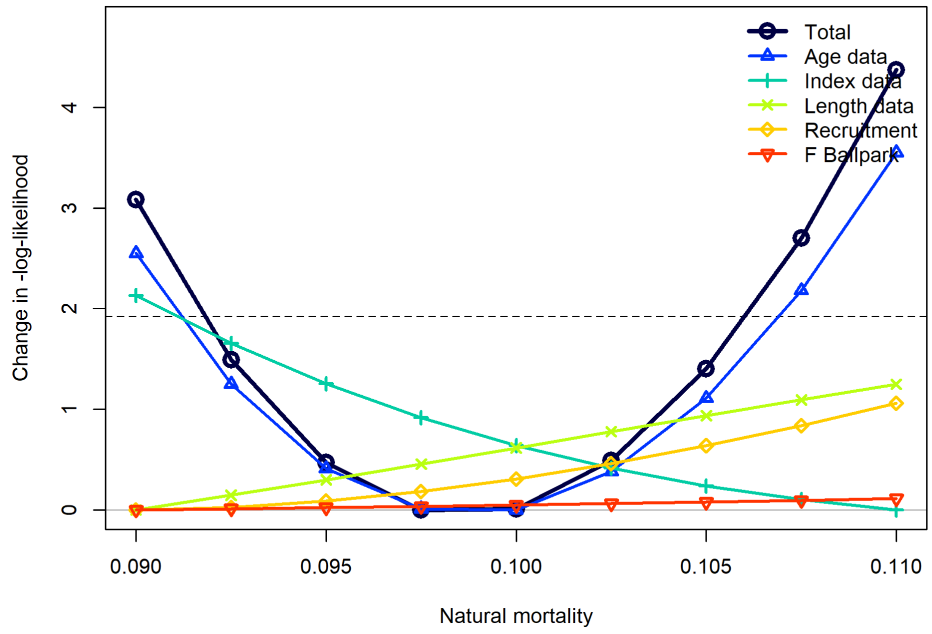

Figure 23. The likelihood profile for natural mortality (*M*), ranging from 0.09 to 0.11. The estimated value for *M* is 0.1065 yr-1.

Table 8. Changes in log-likelihood for the likelihood function (Total) and the contributions from the conditional age at length data (Age), biomass indices (Index), length composition data (Length), estimated recruitment (Recruit) and estimated fishing mortality (F Ballpark) for a likelihood profile on natural mortality (*M*). Minimum values for each component (Total, Age, Index, Length, Recruit and F) are shown in bold. The estimated value of *M* in the 2022 preliminary base-case model is *M*= 0.1065 yr^{-1}.

M	TOTAL	Age	Index	Length	Recruit	F Ballpark
0.0900	3.08	2.55	2.1313	**0.0000**	**0.00000**	**0.00000**
0.0925	1.49	1.25	1.6527	0.1452	0.02548	0.010502
0.0950	0.47	0.41	1.2508	0.2981	0.08754	0.021810
0.0975	**0.00**	0.01	0.9162	0.4557	0.18235	0.034003
0.1000	0.01	**0.00**	0.6405	0.6157	0.30697	0.047172
0.1025	0.49	0.38	0.4166	0.7761	0.45904	0.061418
0.1050	1.40	1.11	0.2385	0.9356	0.63655	0.076855
0.1075	2.70	2.18	0.1011	1.0929	0.83776	0.093610
0.1100	4.37	3.55	**0.000**	1.2471	1.06107	0.111828

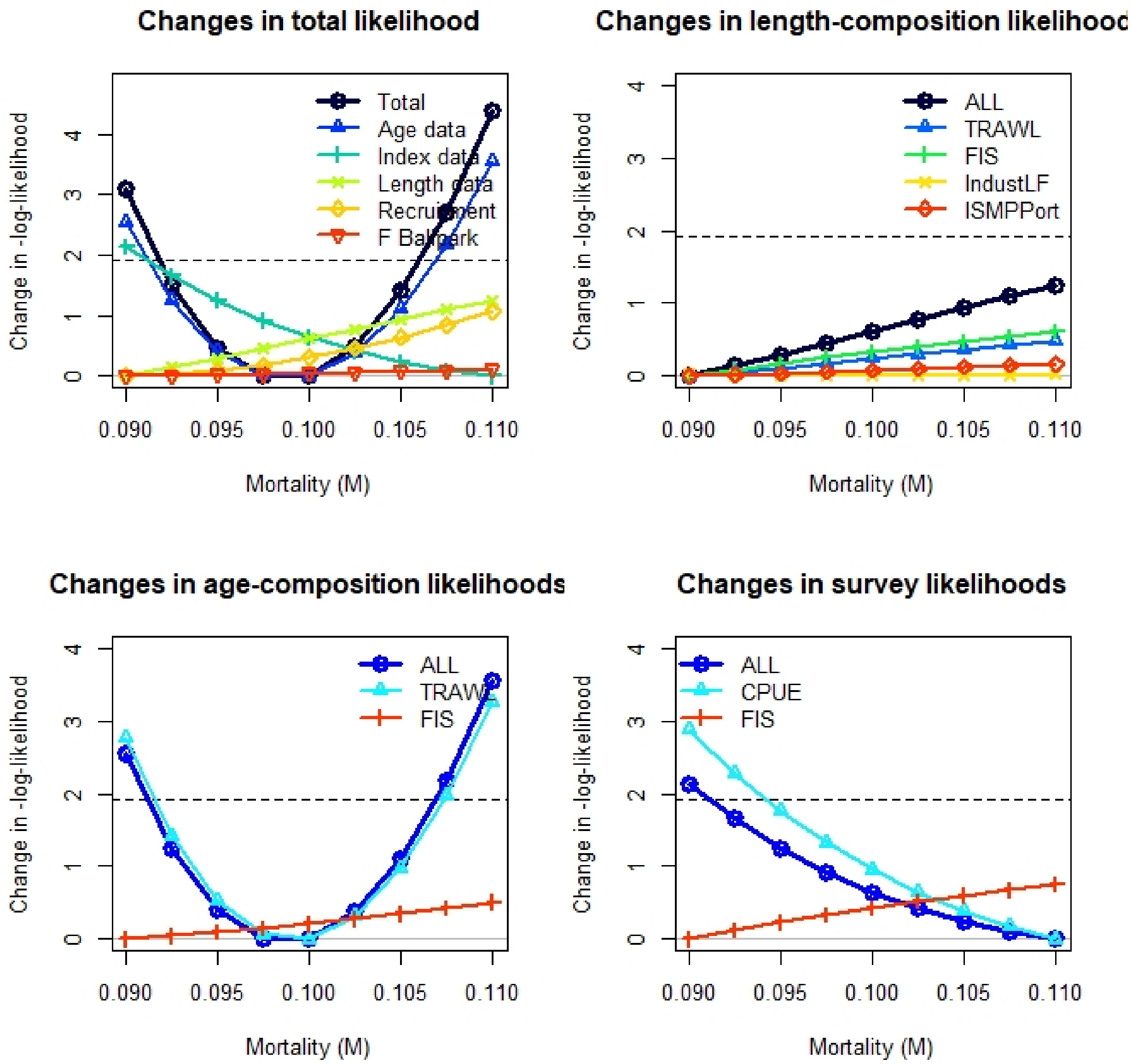

Figure 24. Piner plot for the likelihood profile for natural mortality (*M*), showing components of the change in likelihood for length, age and indices (CPUE; GAB-FIS) in addition to the changes in the total likelihood.

7.1.2 Steepness (*h*)

A likelihood profile on stock recruitment steepness, *h*, shows the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours (Figure 25). This figure shows that *h* is not well defined, as the 95% confidence limits are not crossed (log-likelihood of 1.92 on the y-axis) by the total likelihood within the range of values considered (*h* = 0.6 to 0.8). This is not surprising given the stock has not been depleted and then subsequently recovered to provide the information that would assist in the estimation of steepness. It is therefore reasonable to fix steepness at 0.75, the default value assumed in other SESSF assessments

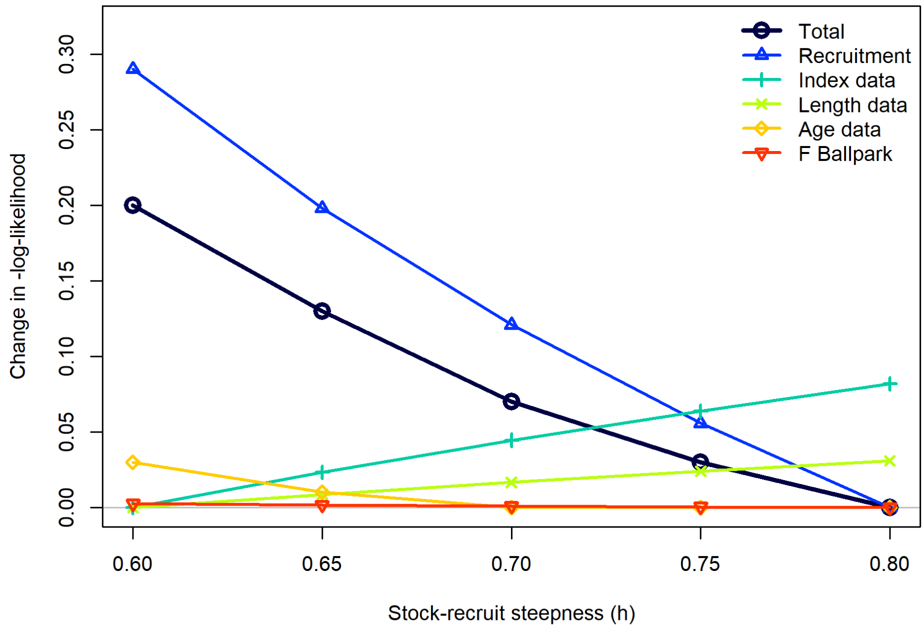

Figure 25. The likelihood profile for steepness (*h*), ranging from 0.6 to 0.8. The fixed value for *h* is 0.75.

8 Appendix

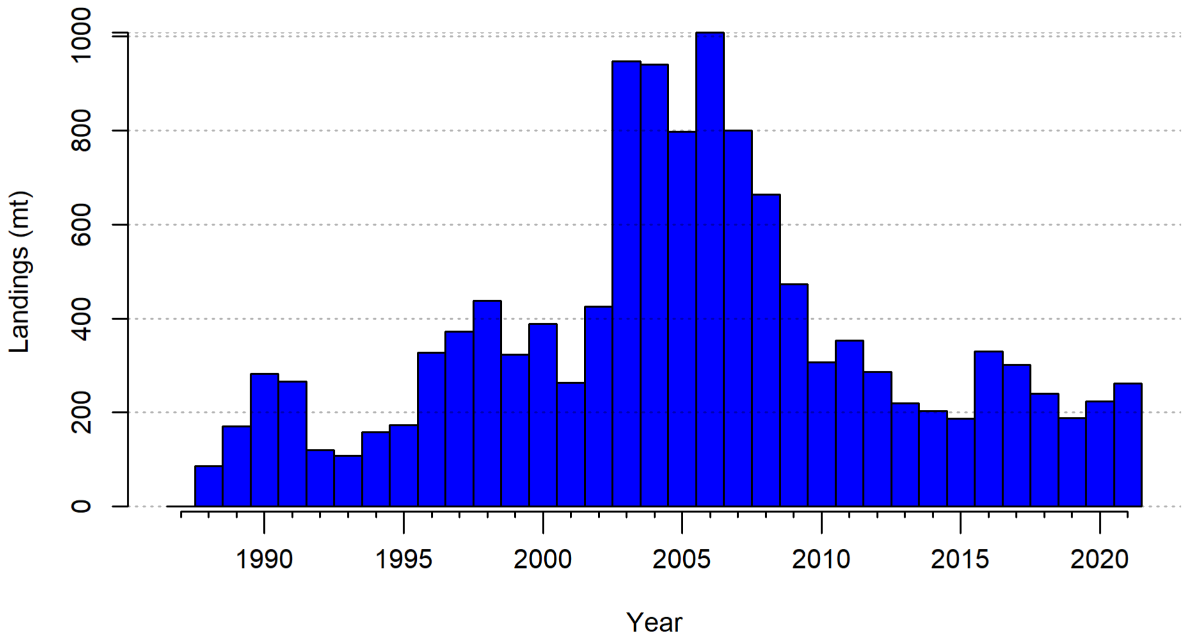

Figure 26. Summary of landed catch by fleet.

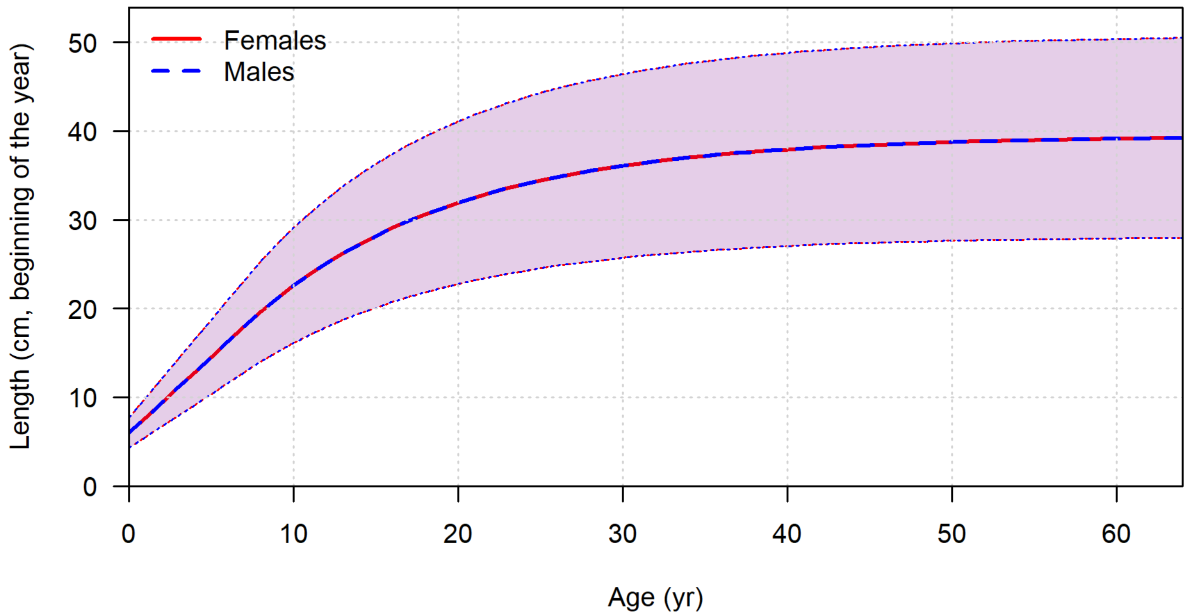

Figure 27. Estimated growth curve for the preliminary base case.

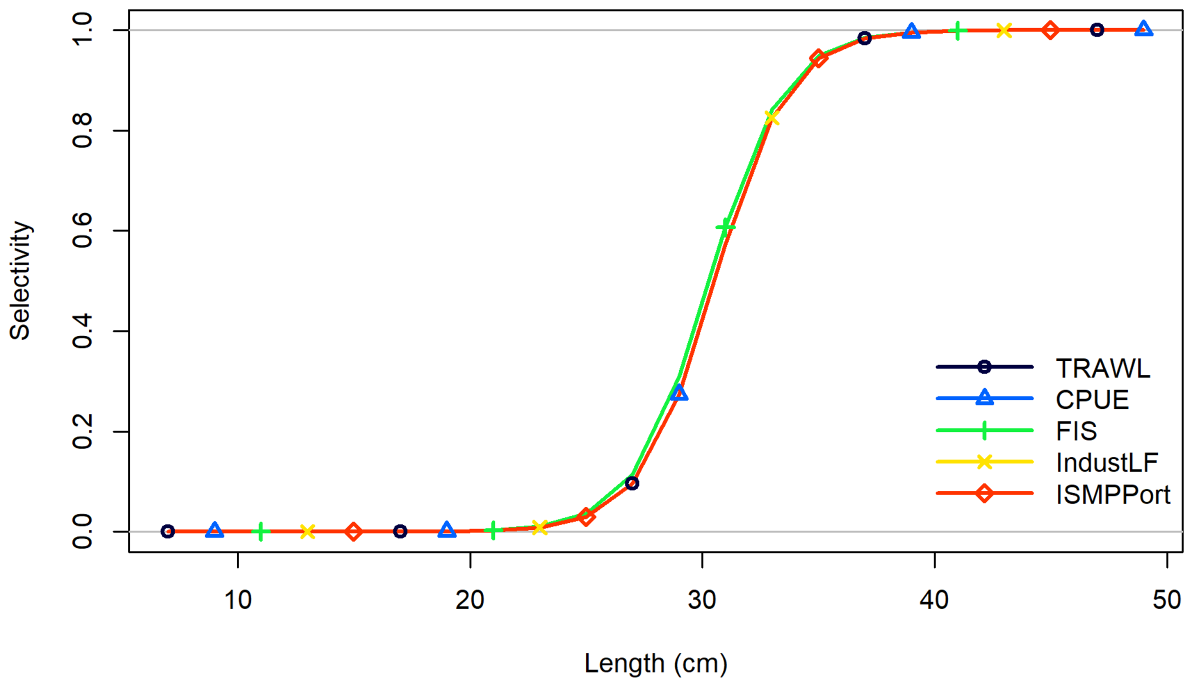

Figure 28. Estimated length based selectivity by fleet.

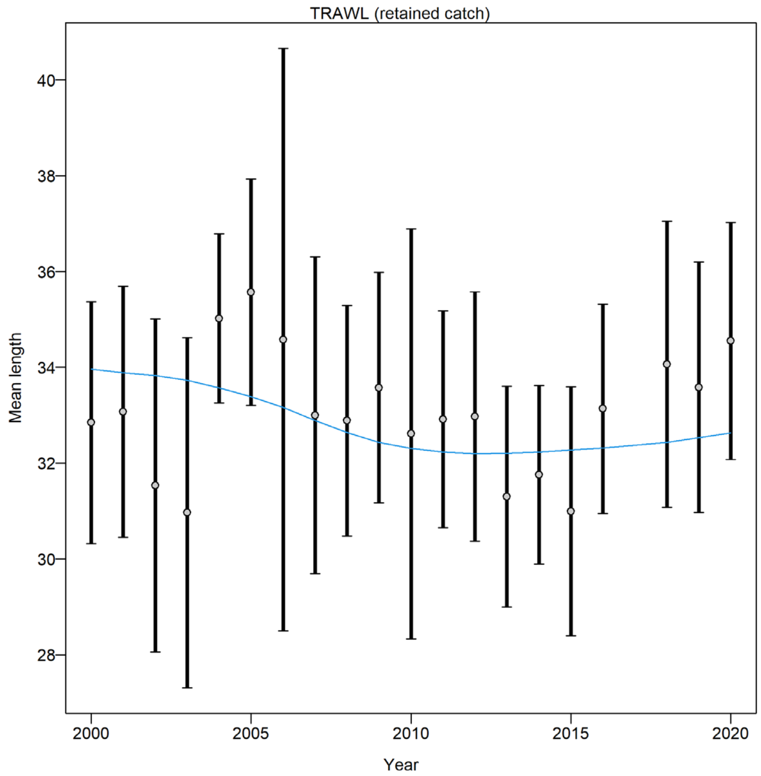

Figure 29. Mean length for Trawl samples with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for age data is 0.9995 (0.7208-1.8408).

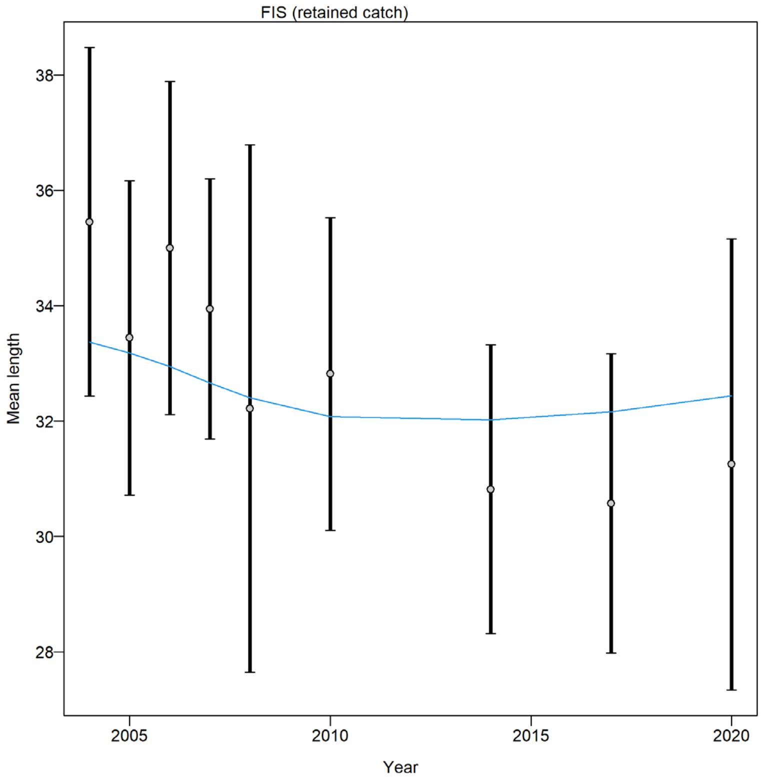

Figure 30. Mean length for FIS samples with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for age data is 1.0003 (0.6891-2.7043).

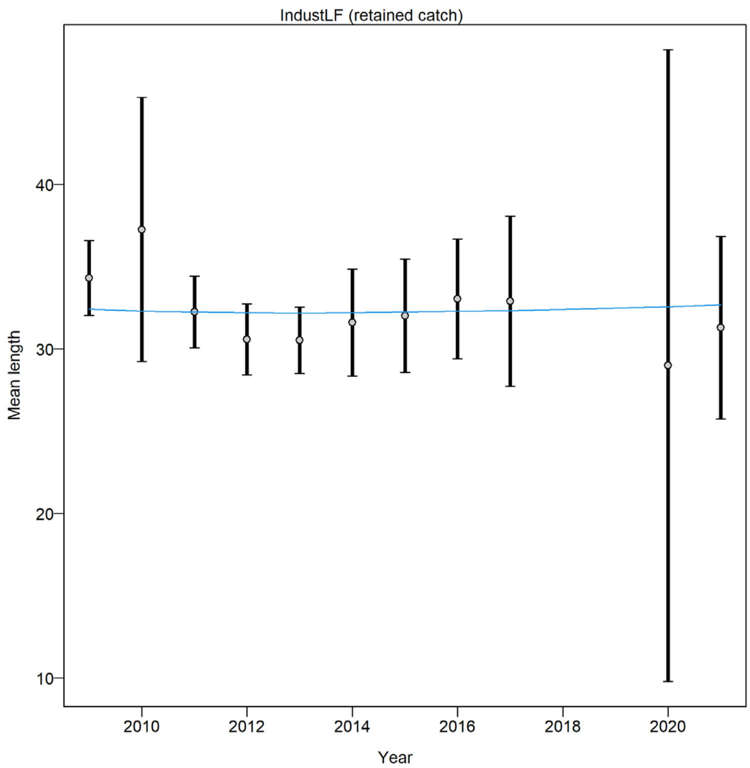

Figure 31. Mean length for Industrial LF samples with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for age data is 1.0003 (0.6891-2.7043).

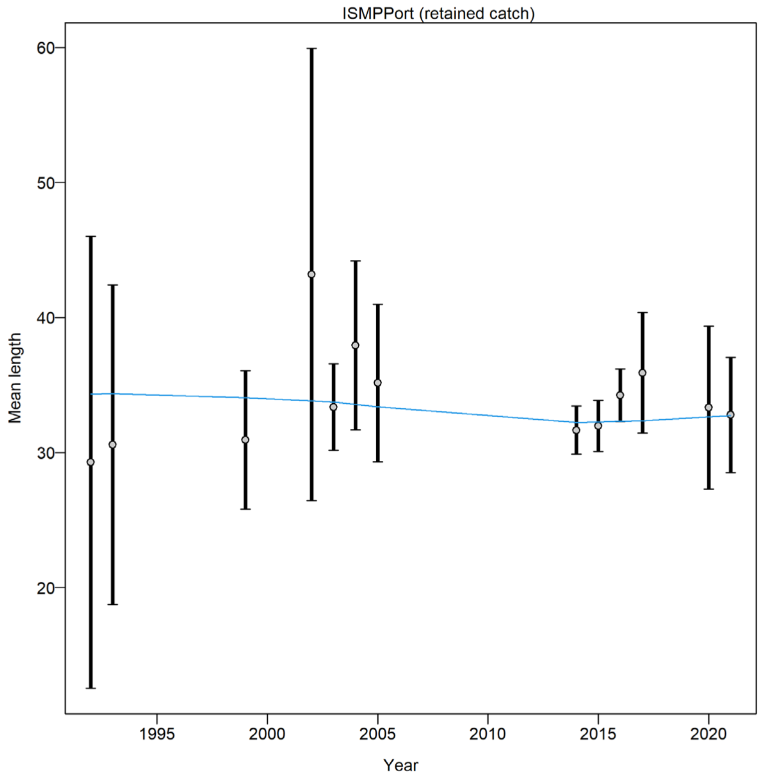

Figure 32. Mean length for ISMPPort samples with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for age data is 1 (0.5998-3.552).

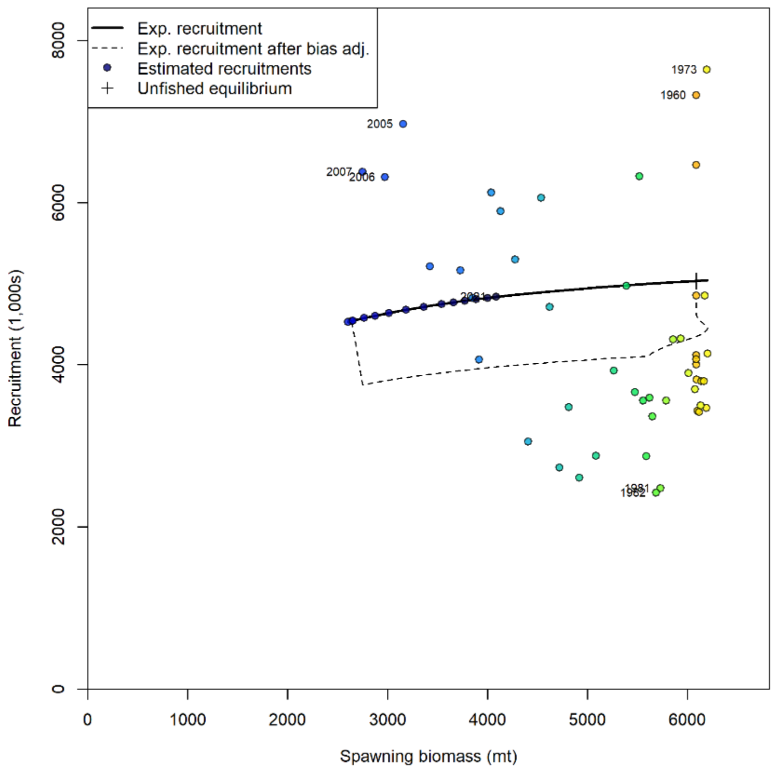

Figure 33. Time series showing stock recruitment curve.

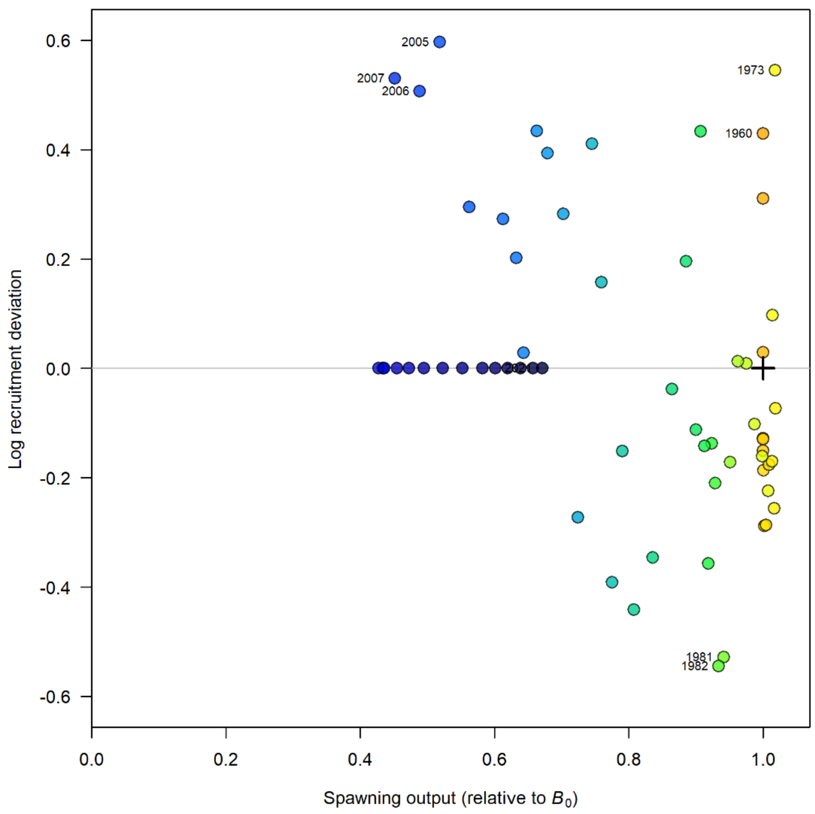

Figure 34. Time series showing stock recruitment deviations.

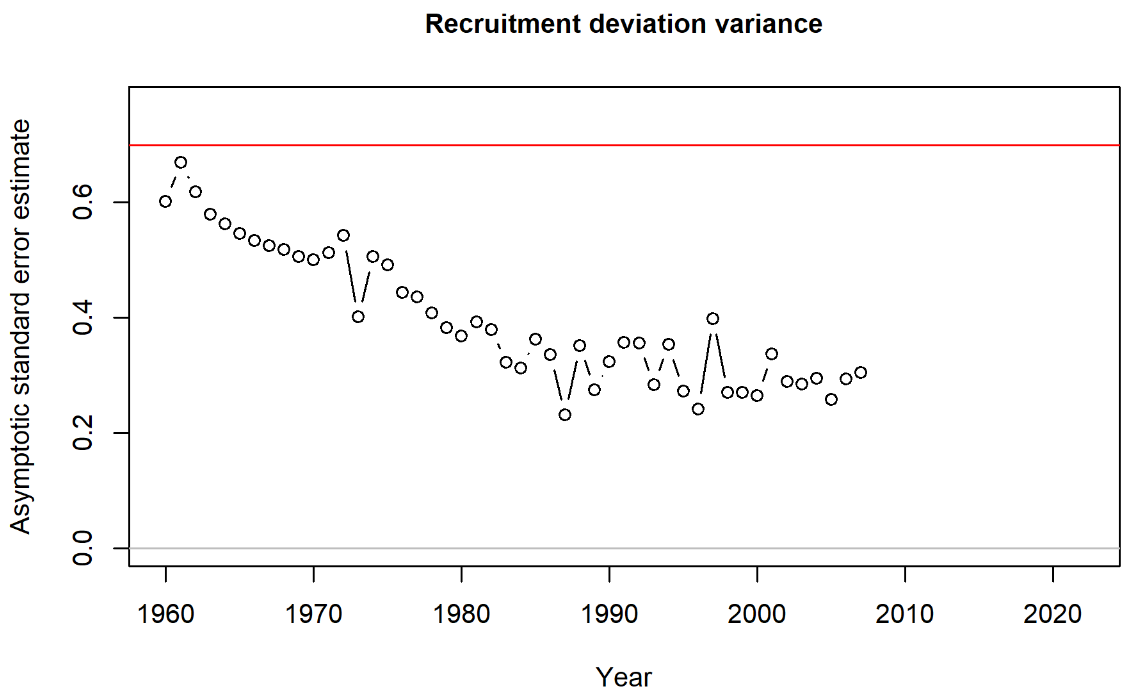

Figure 35. Recruitment deviation variance.

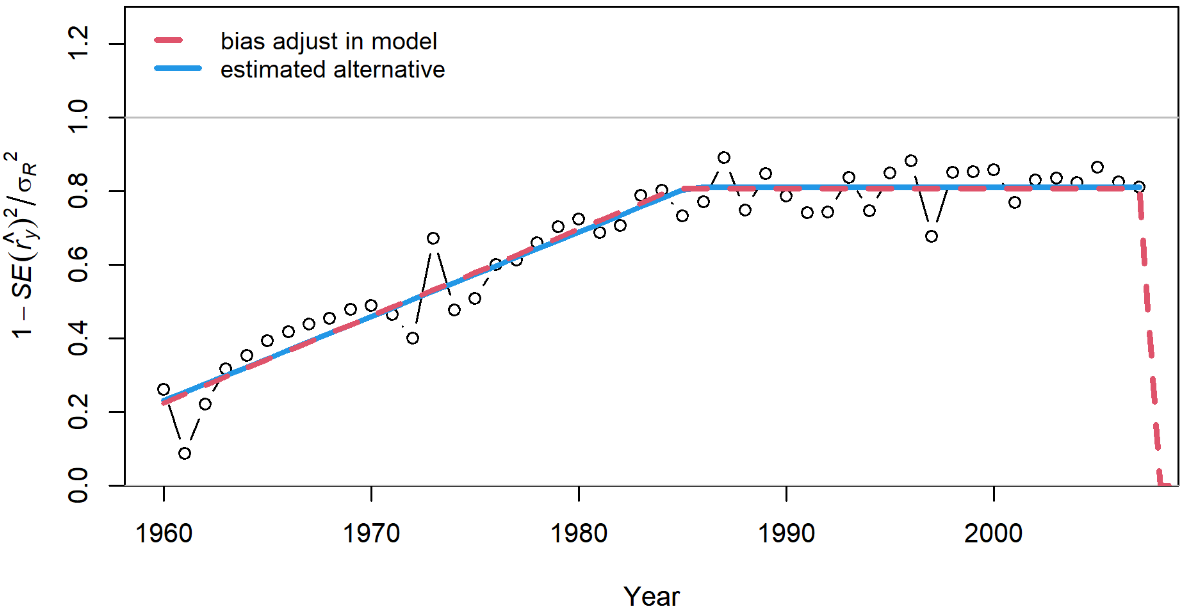

Figure 36. Recruitment deviation bias ramp adjustment.

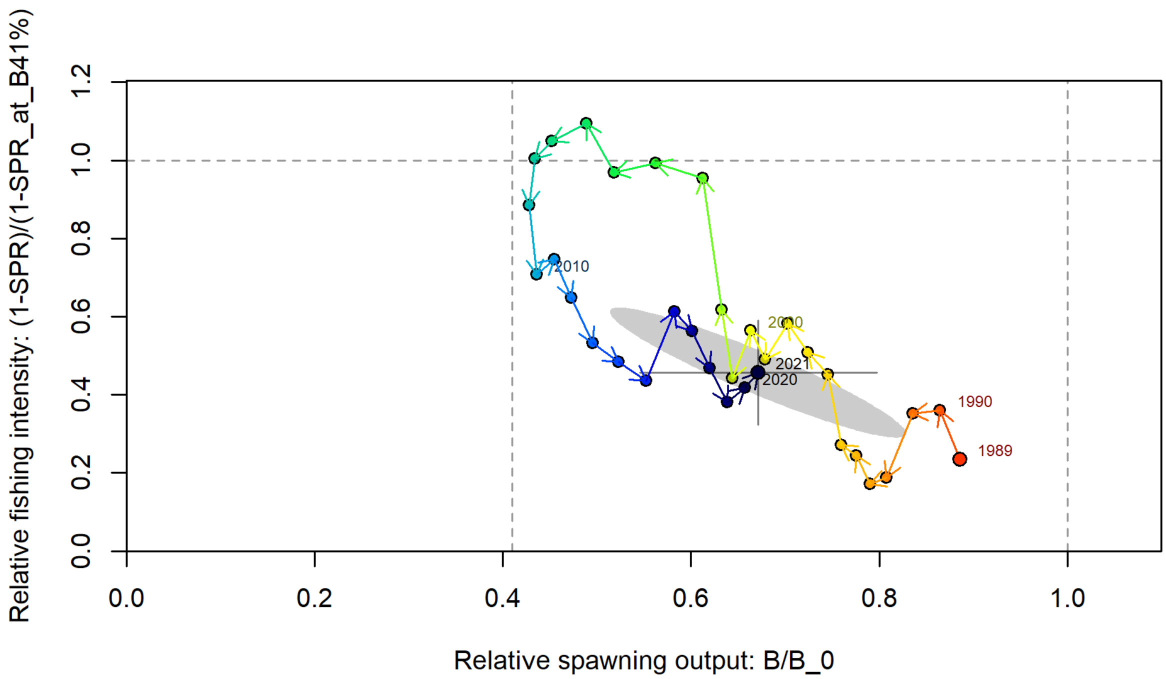

Figure 37. Phase plot of biomass vs SPR ratio.

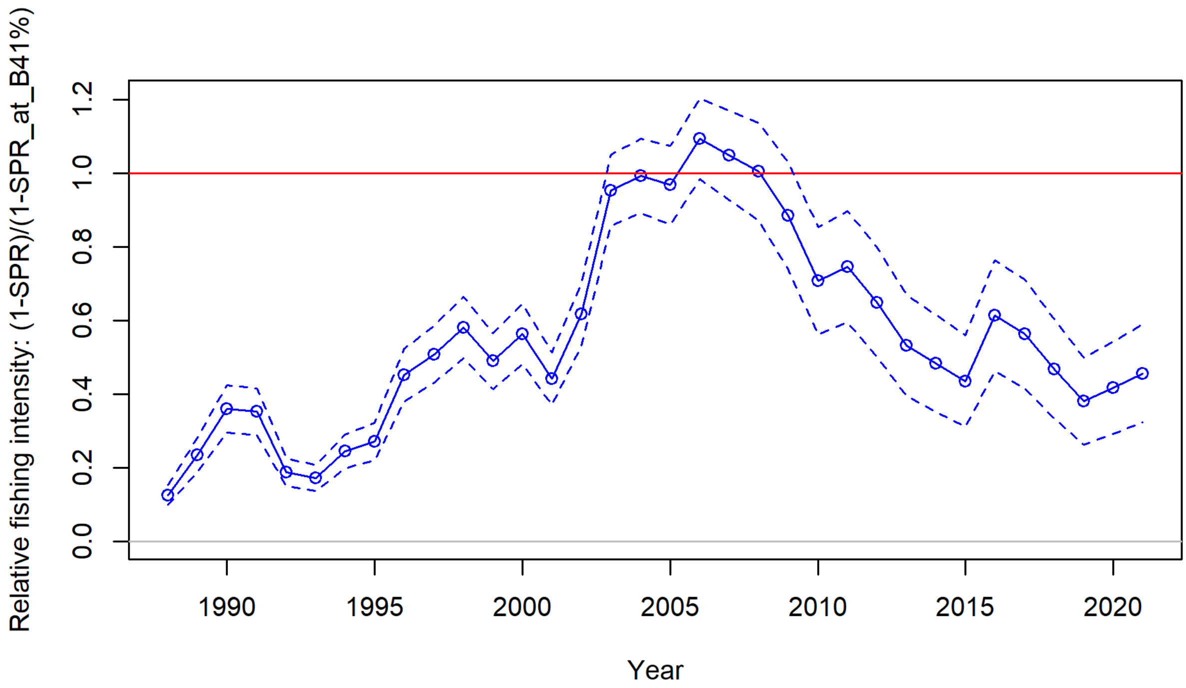

Figure 38. SPR ratio through time, the red line represents the target fishing mortality and each point is a year in the model, starting on the left hand side of the figure.

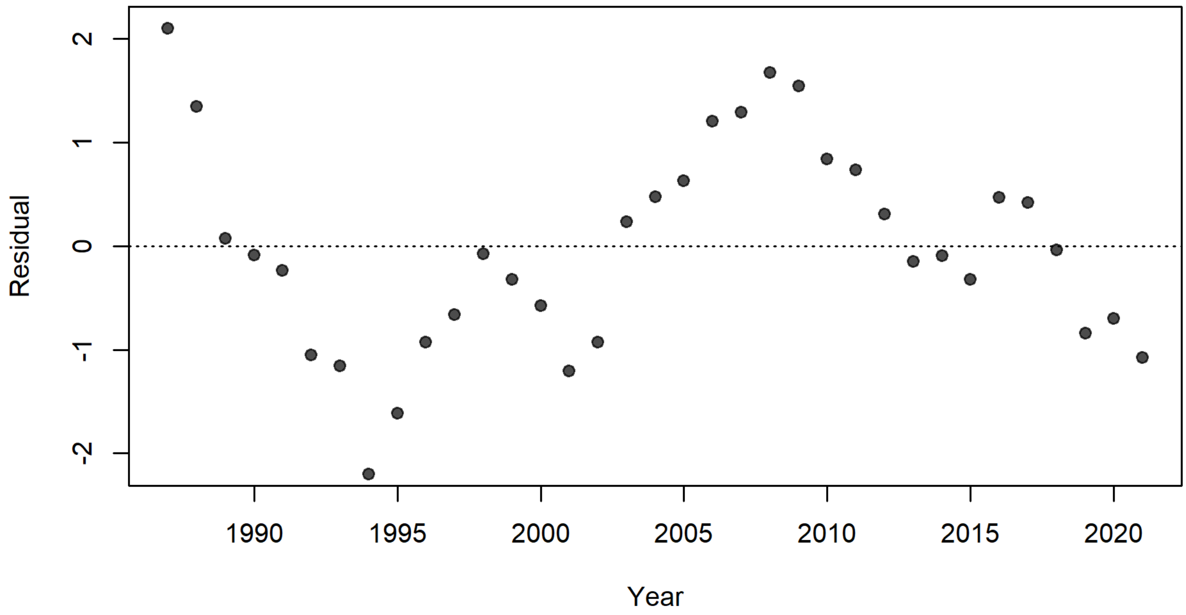

Figure 39. Residuals for fits to CPUE for the trawl fleet.

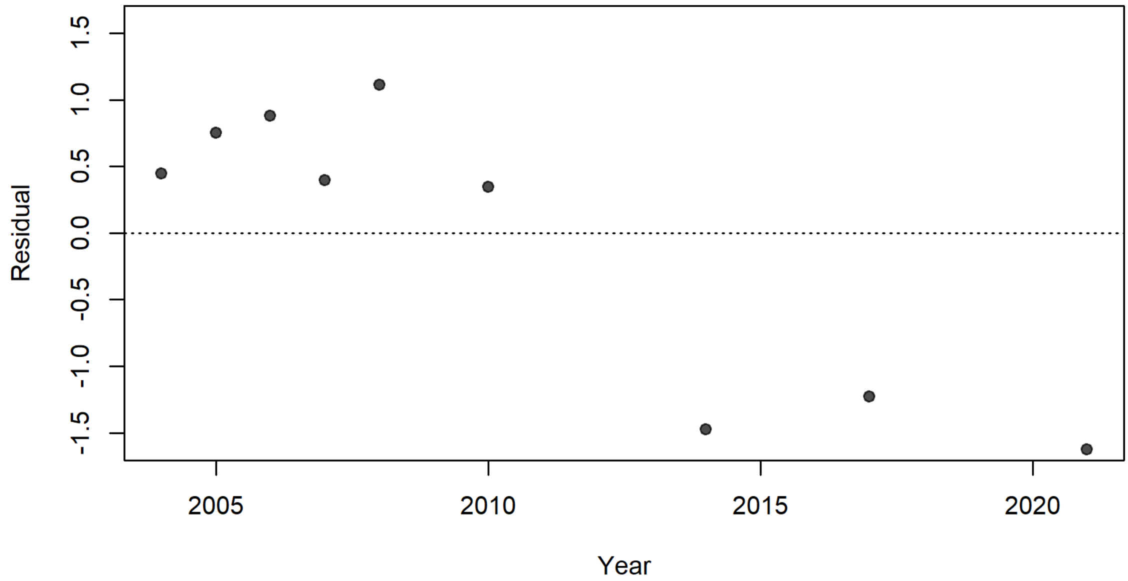

Figure 40. Residuals for fits to FIS indices.

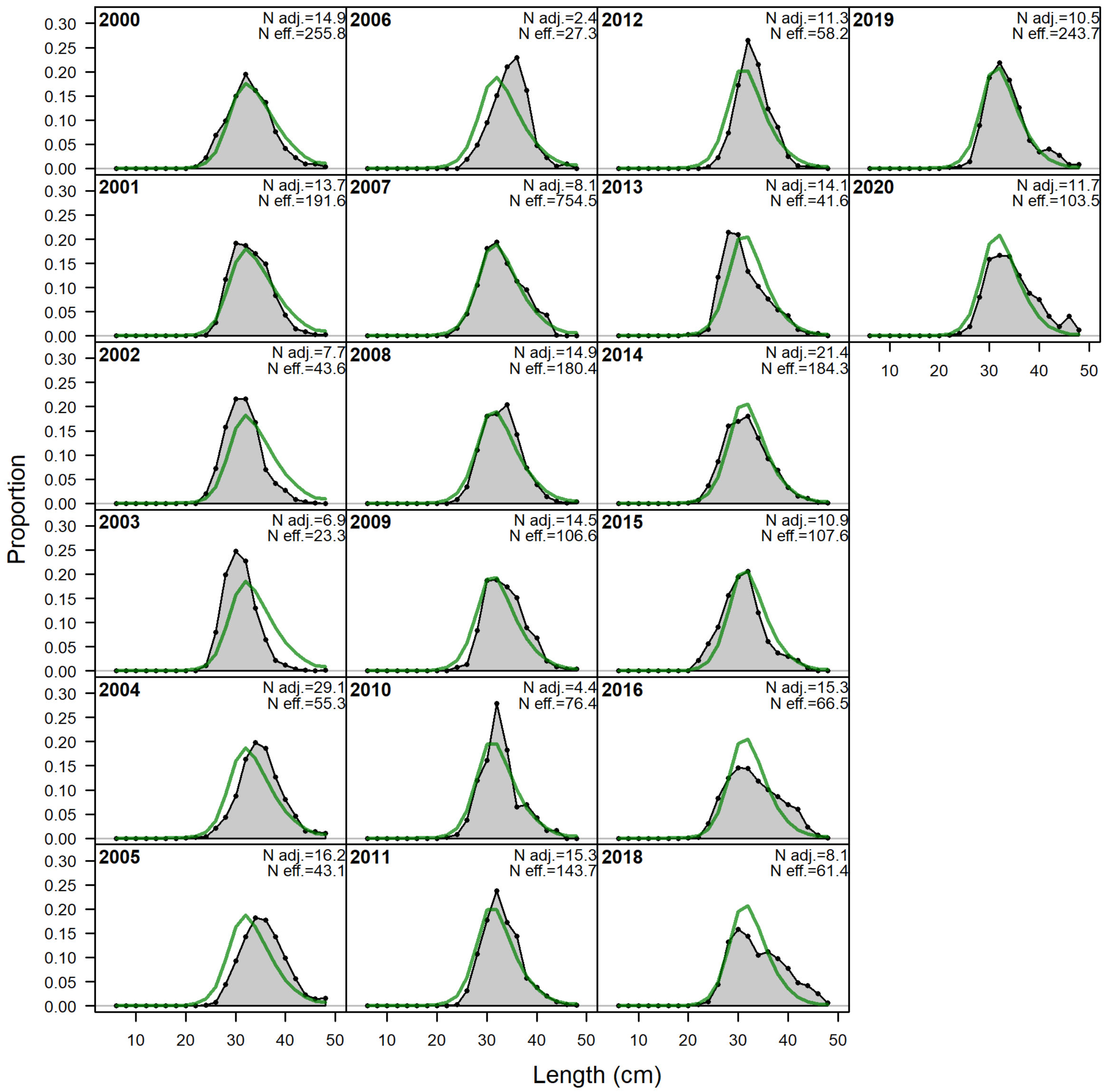

Figure 41. Fits to onboard retained length compositions for the trawl fleet.

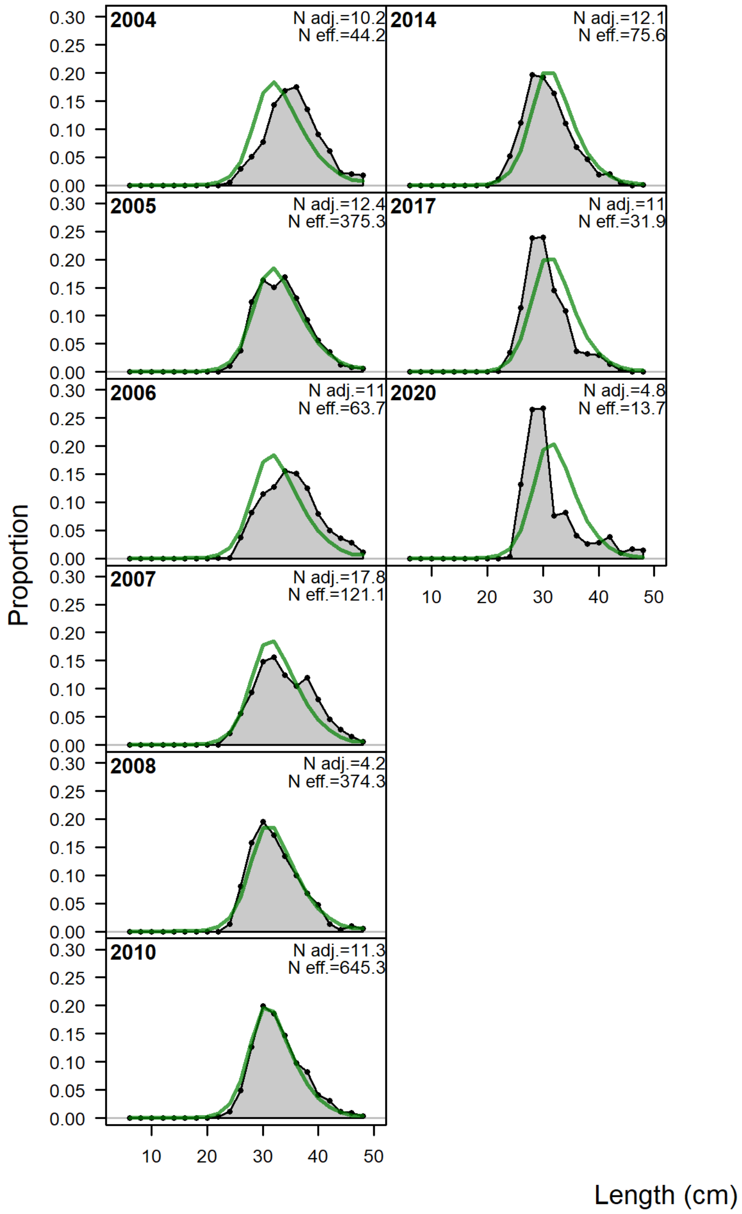

Figure 42. Fits to onboard retained length compositions for the GAB-FIS fleet.

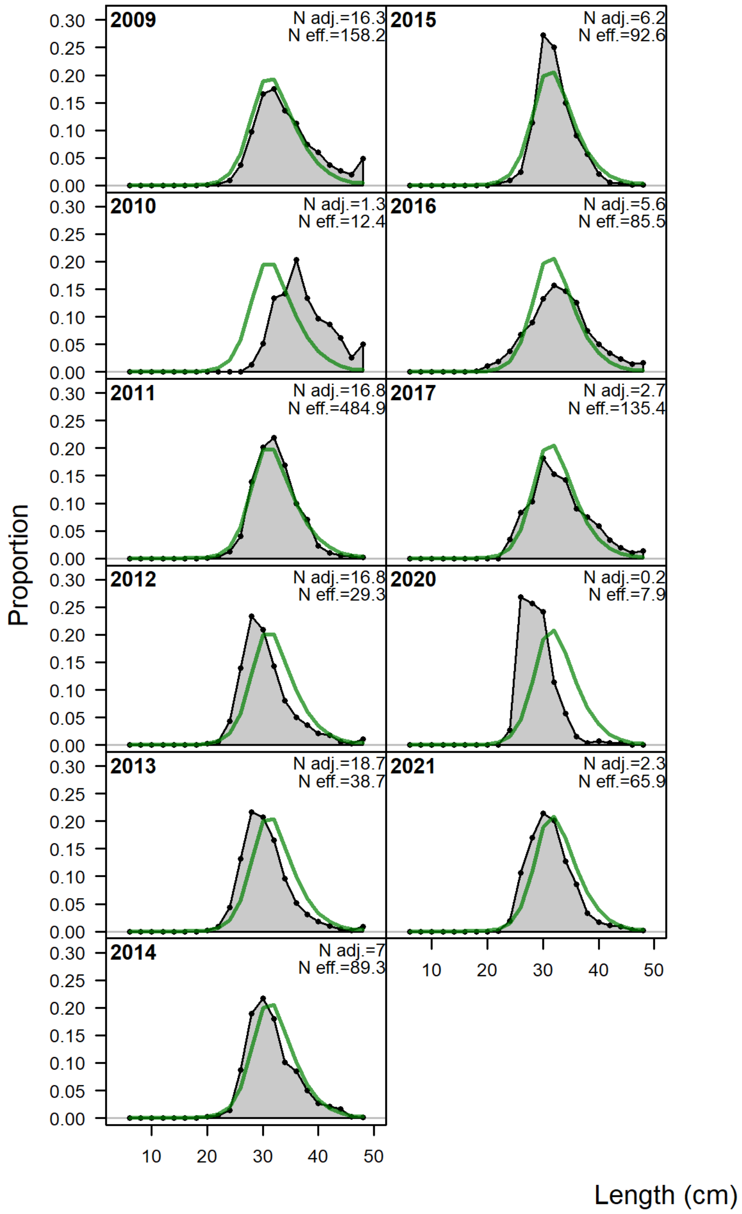

Figure 43. Fits to port retained length compositions for the industry fleet.

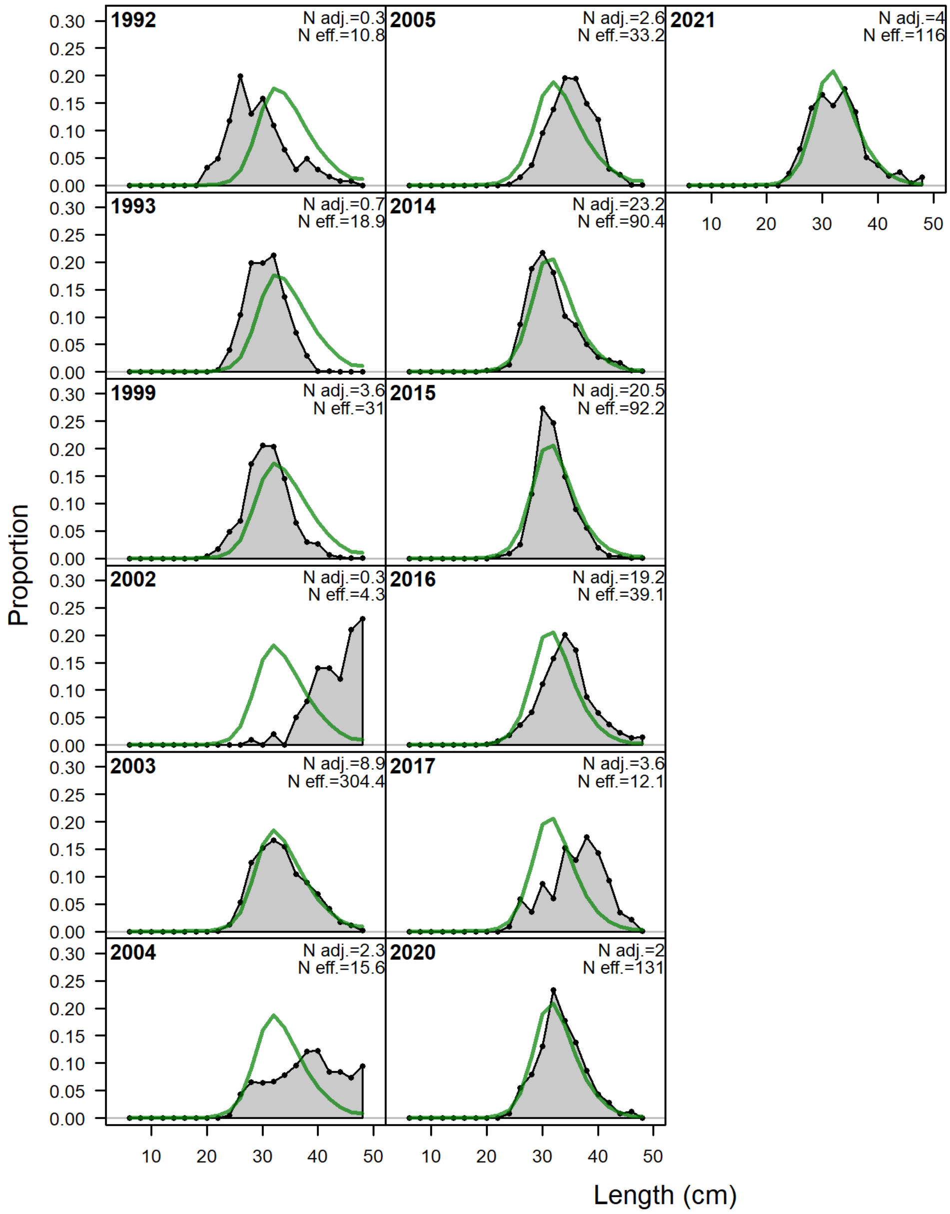

Figure 44. Fits to port retained length compositions for the ISMP fleet.

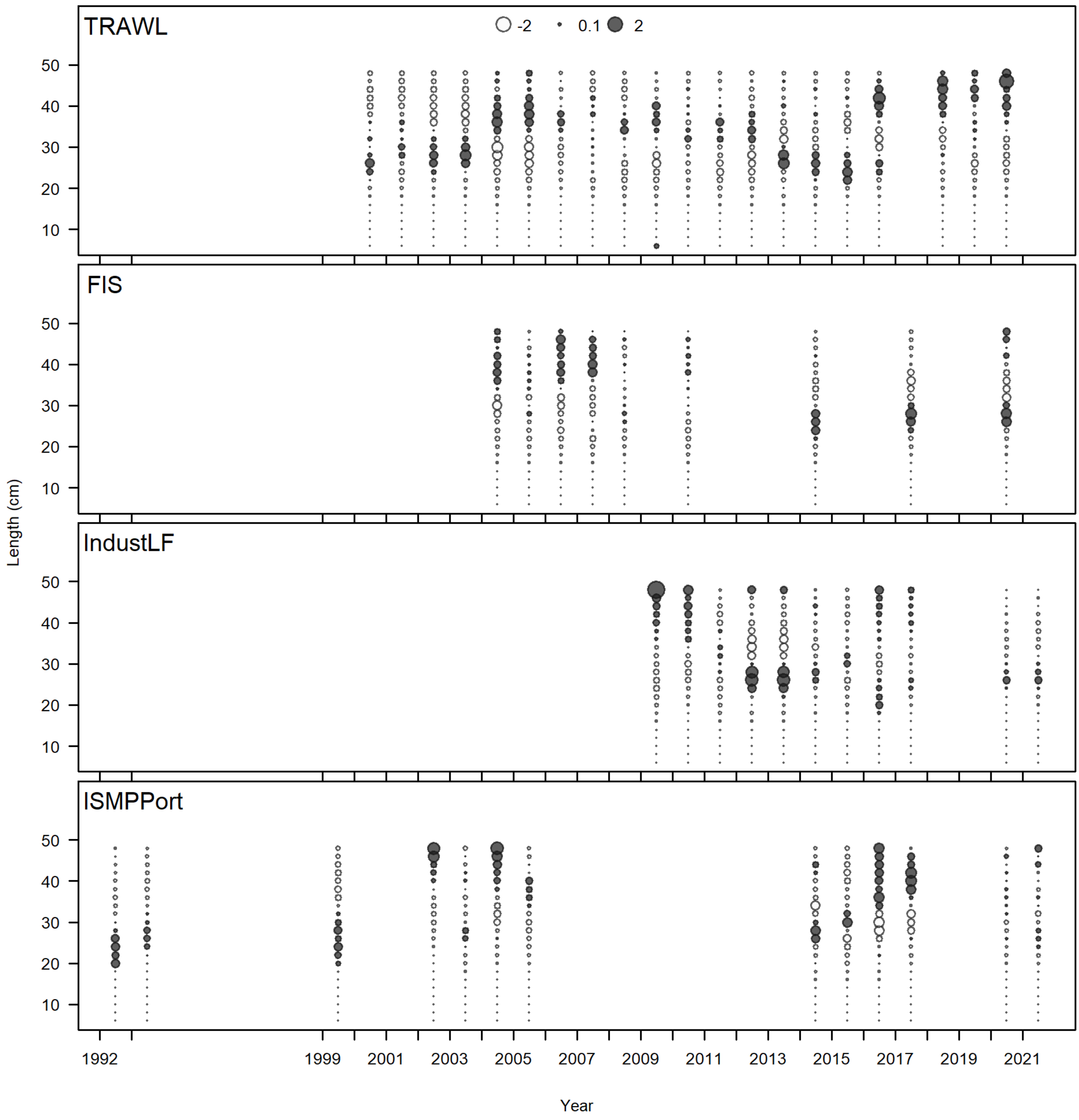

Figure 45. Residuals of fits to the annual length compositions data for all fleets.

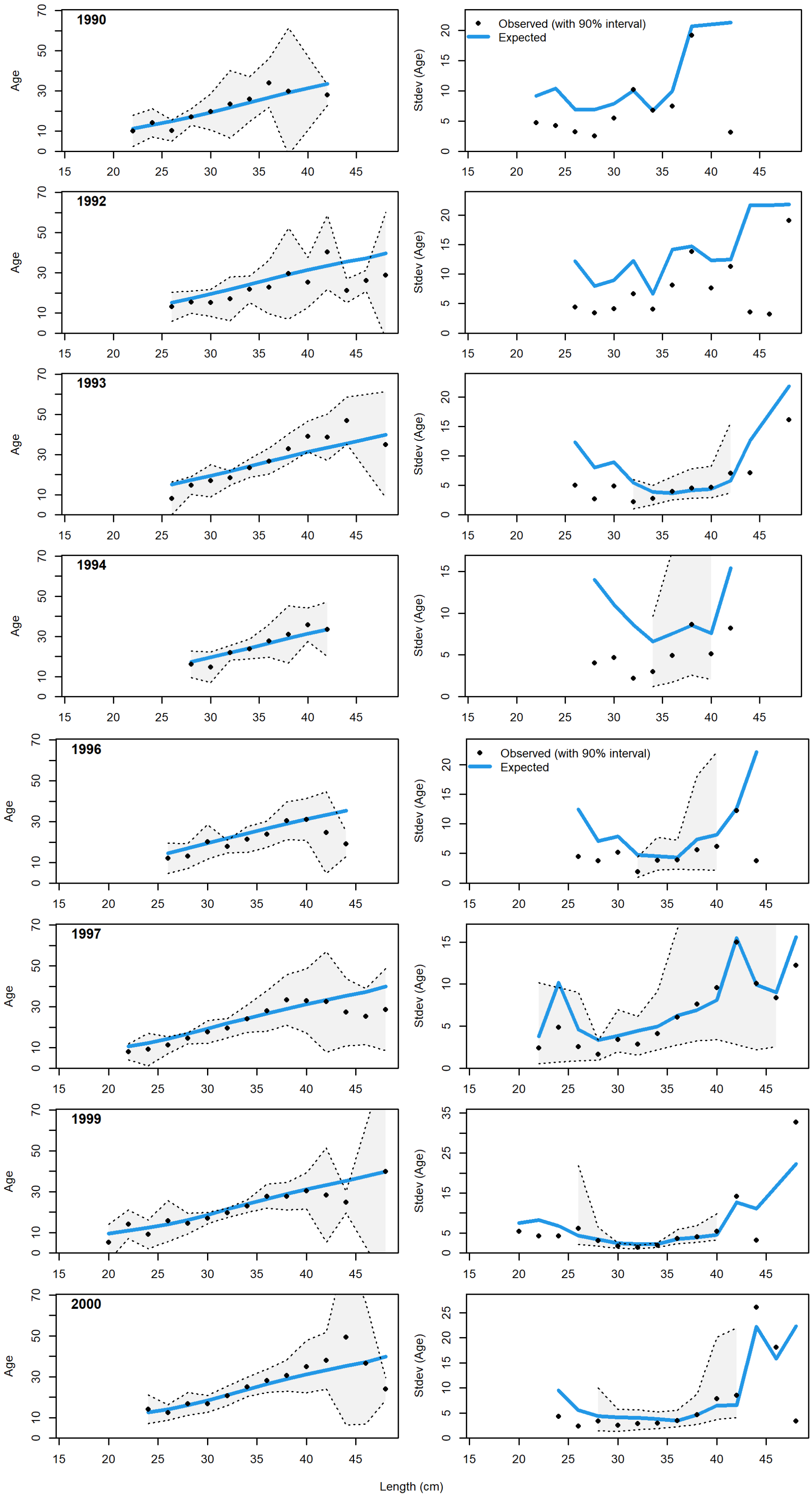

Figure 46. Fits to conditional age at length data for the trawl fleet (1990-2000).

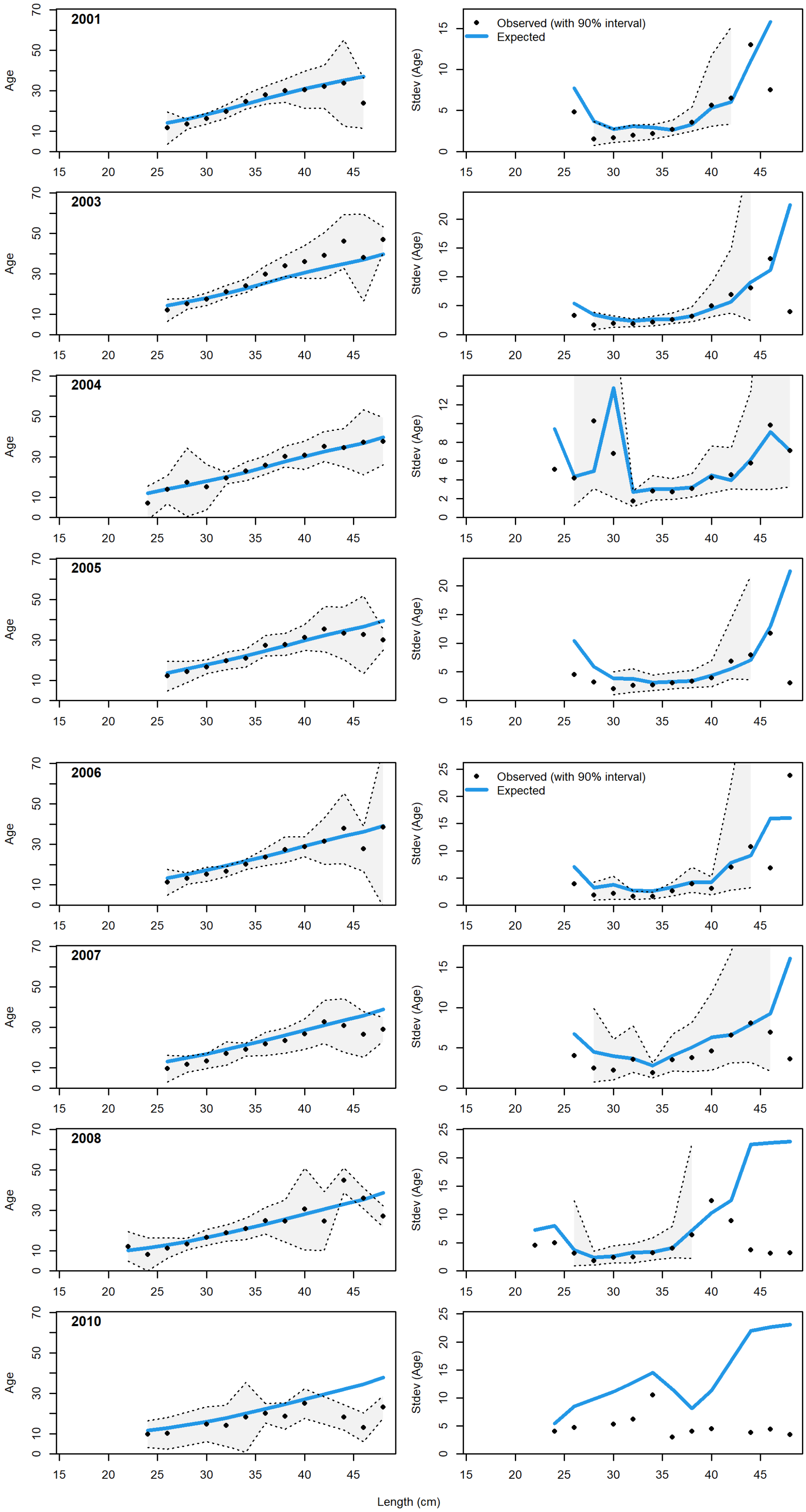

Figure 47. Fits to conditional age at length data for the trawl fleet (2001-2010).

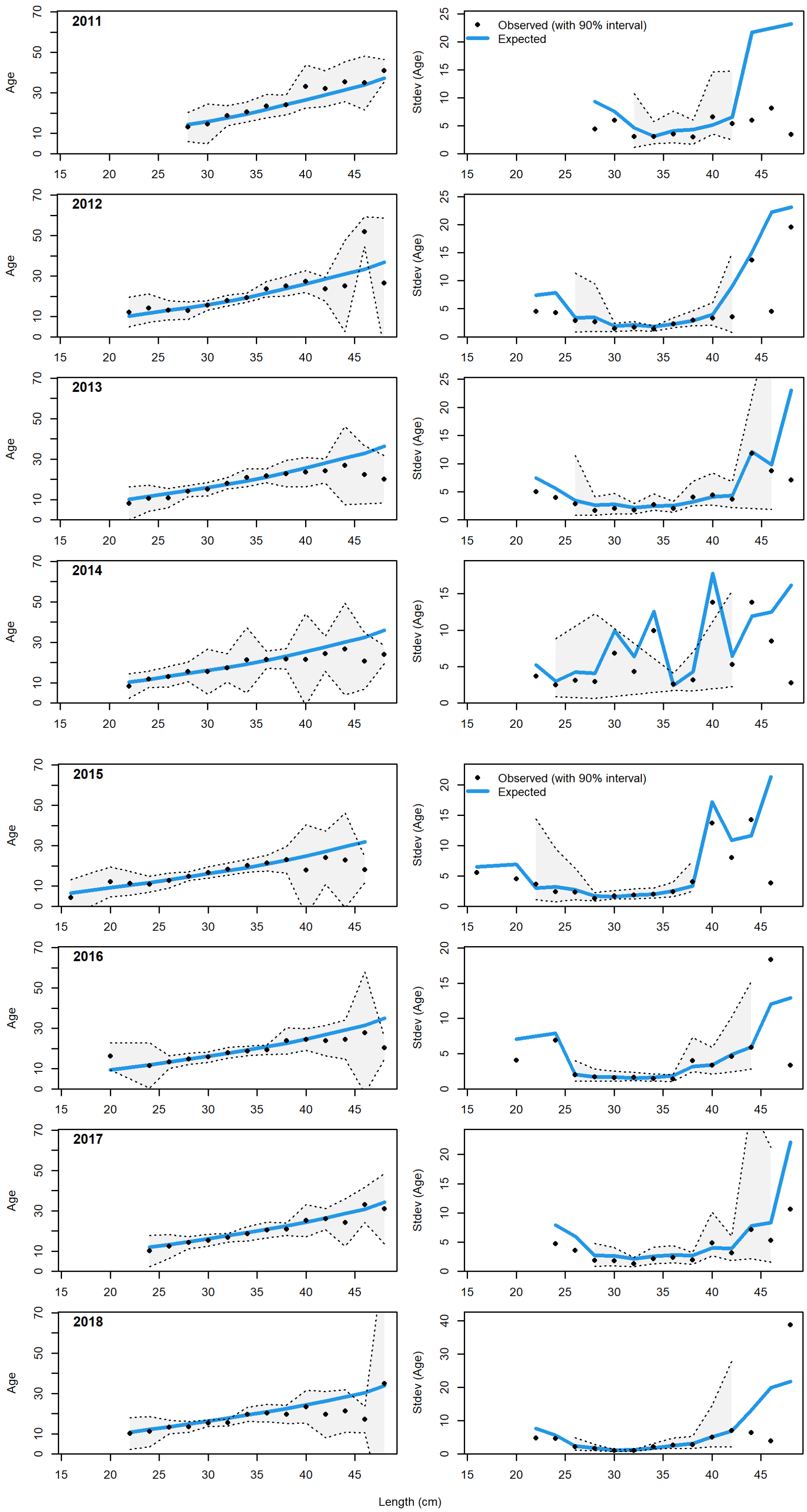

Figure 48. Fits to conditional age at length data for the trawl fleet (2011-2018).

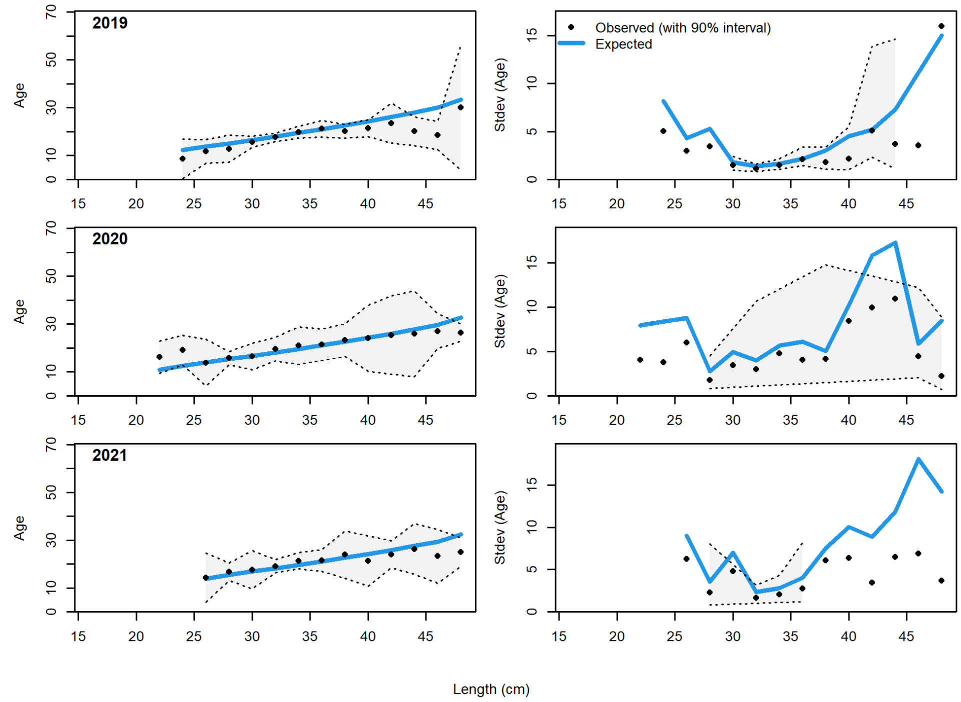

Figure 49. Fits to conditional age at length data for the trawl fleet (2019-2021).

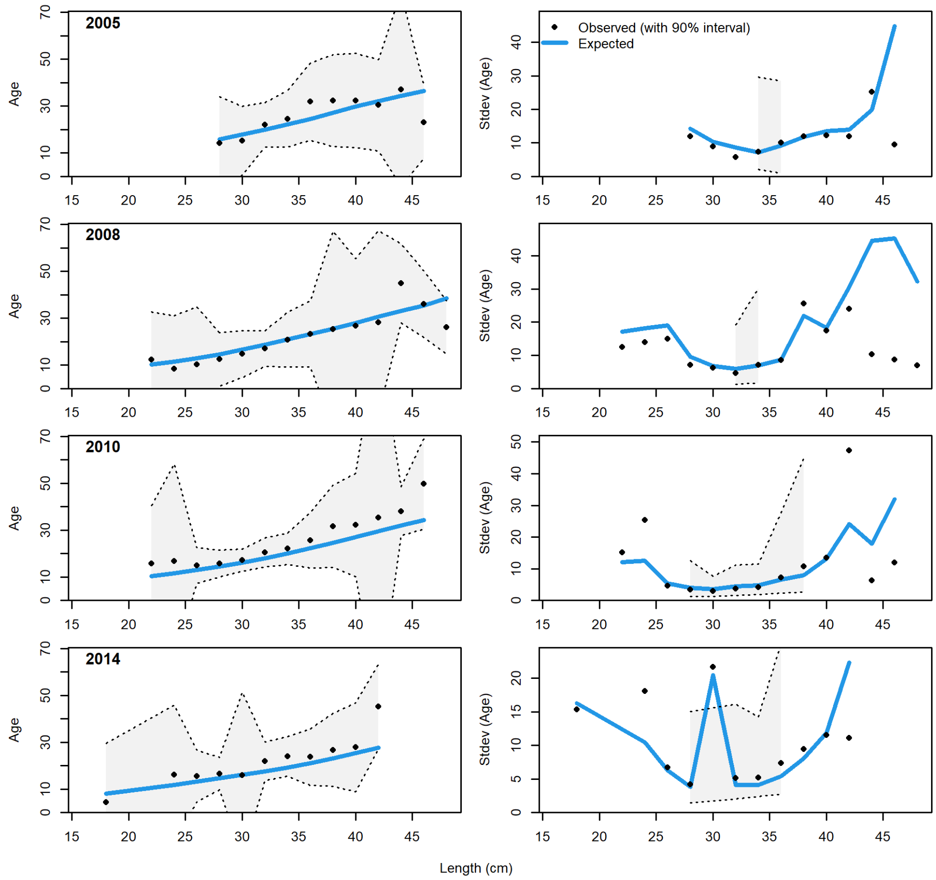

Figure 50. Fits to conditional age at length data for the GAB-FIS fleet (2005-2014).

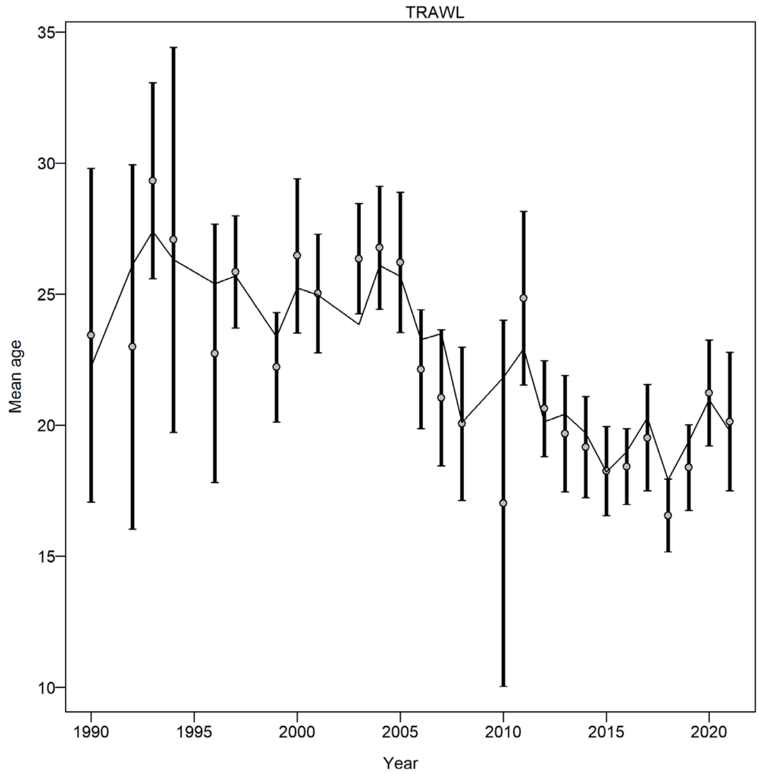

Figure 51. Mean age for male and female samples with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for age data is 1.0007 (0.6505-1.8946).

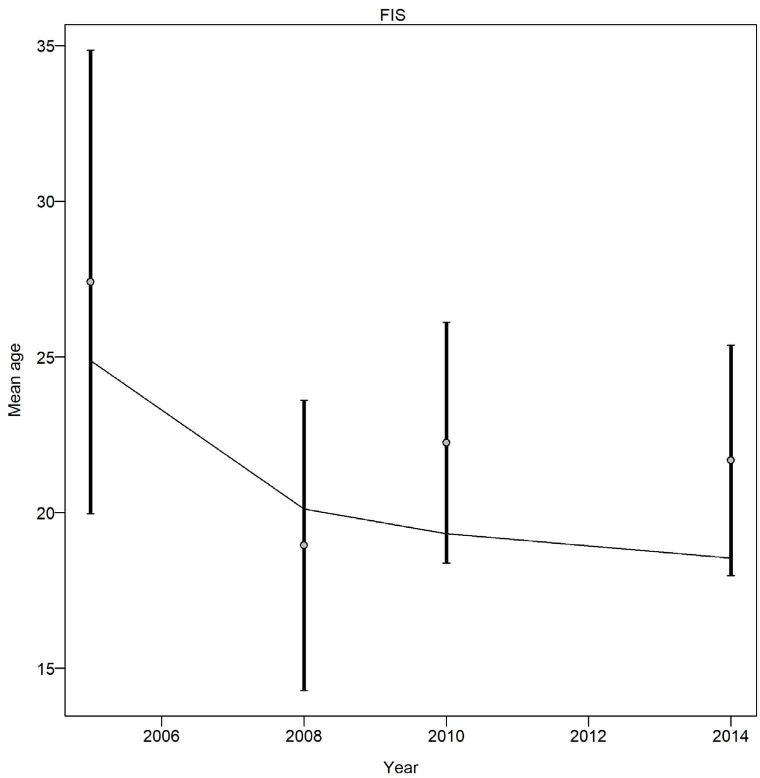

Figure 52. Mean age for male and female samples with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for age data is 0.9989 (0.6756-119.1393).

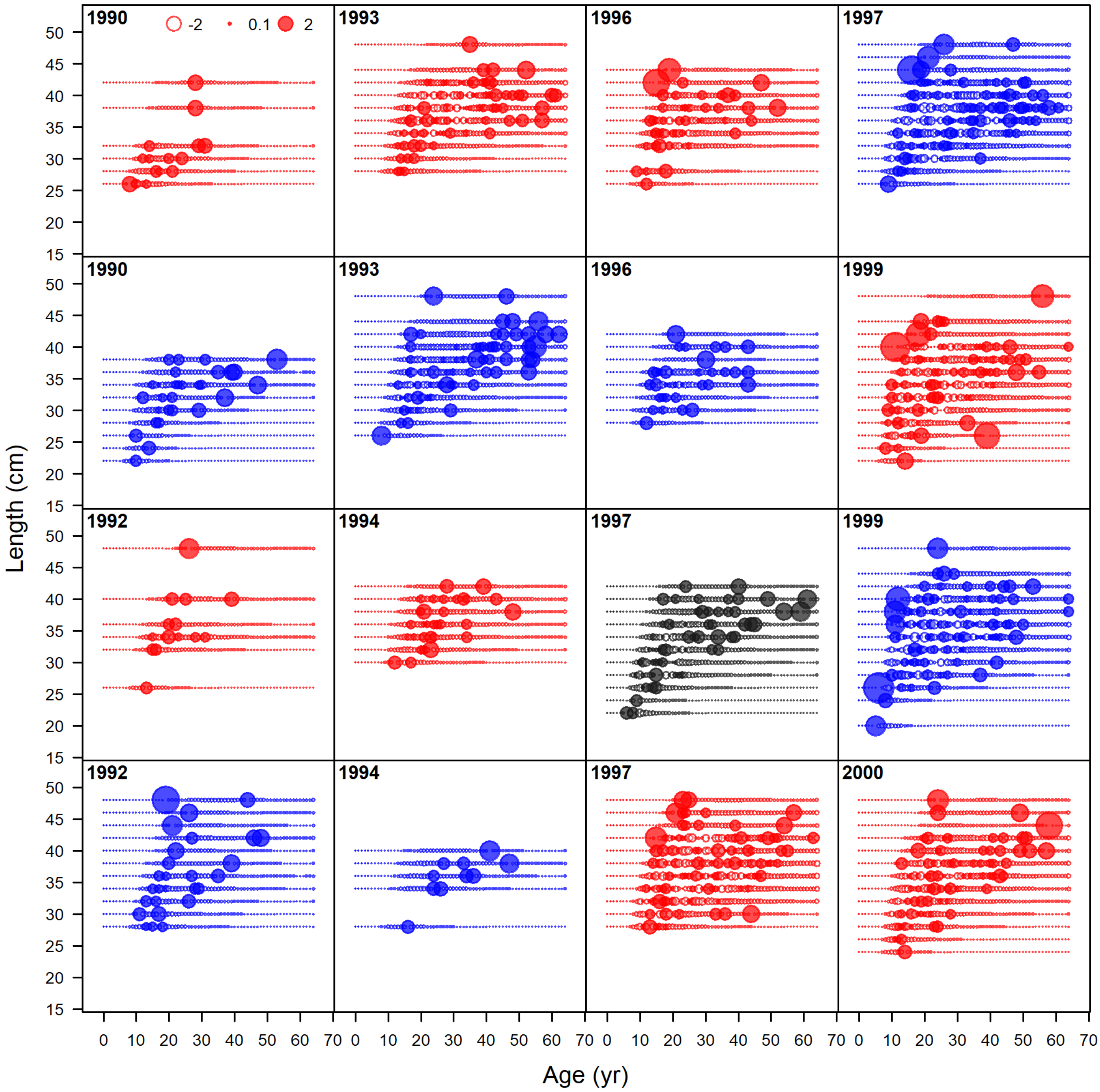

Figure 53. Pearson residuals of conditional age at length data for the trawl fleet. Red dots are females, blue is males and grey is unknown sex.

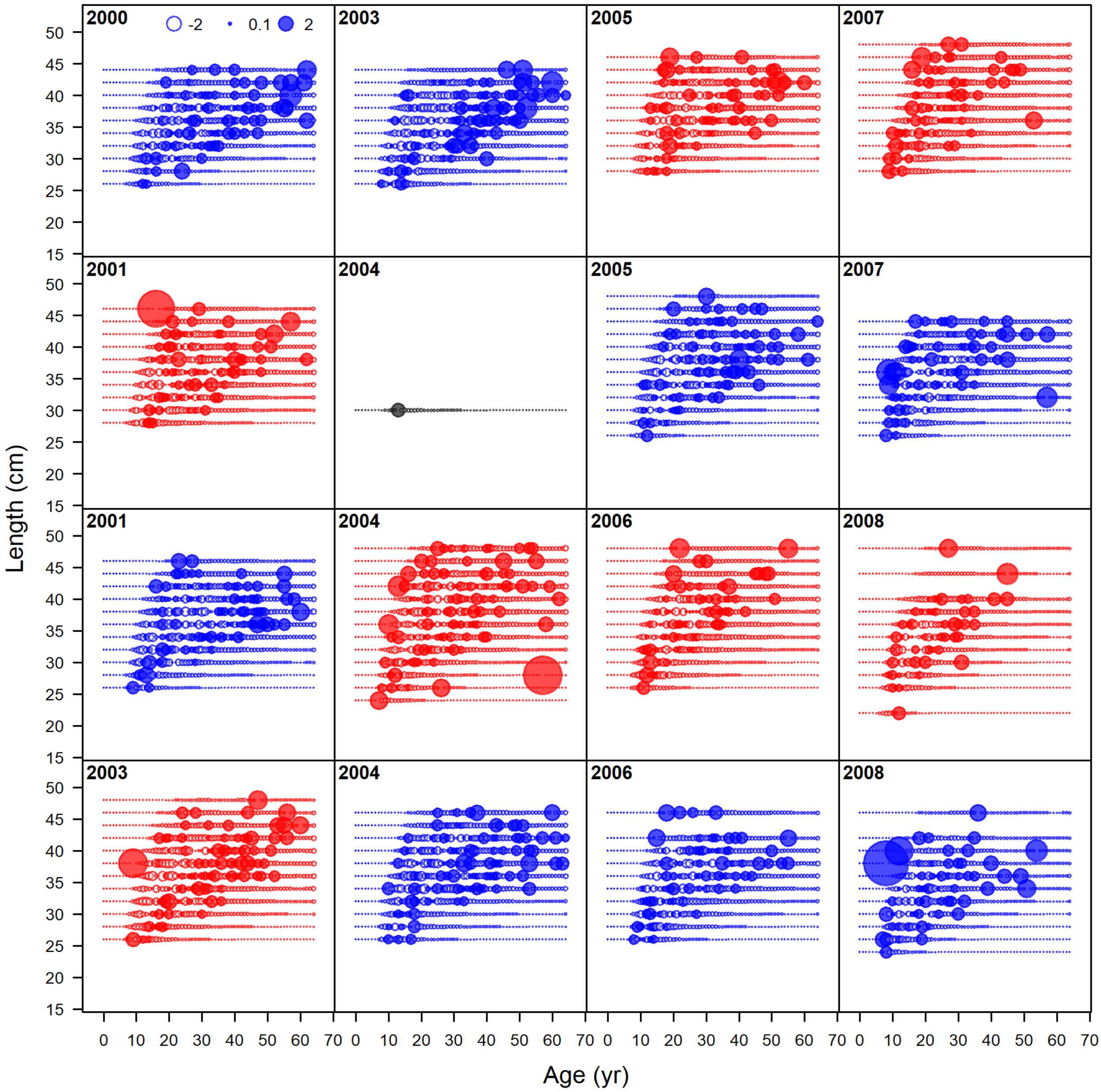

Figure 54. Pearson residuals of conditional age at length data for the trawl fleet. Red dots are females, blue is males and grey is unknown sex.

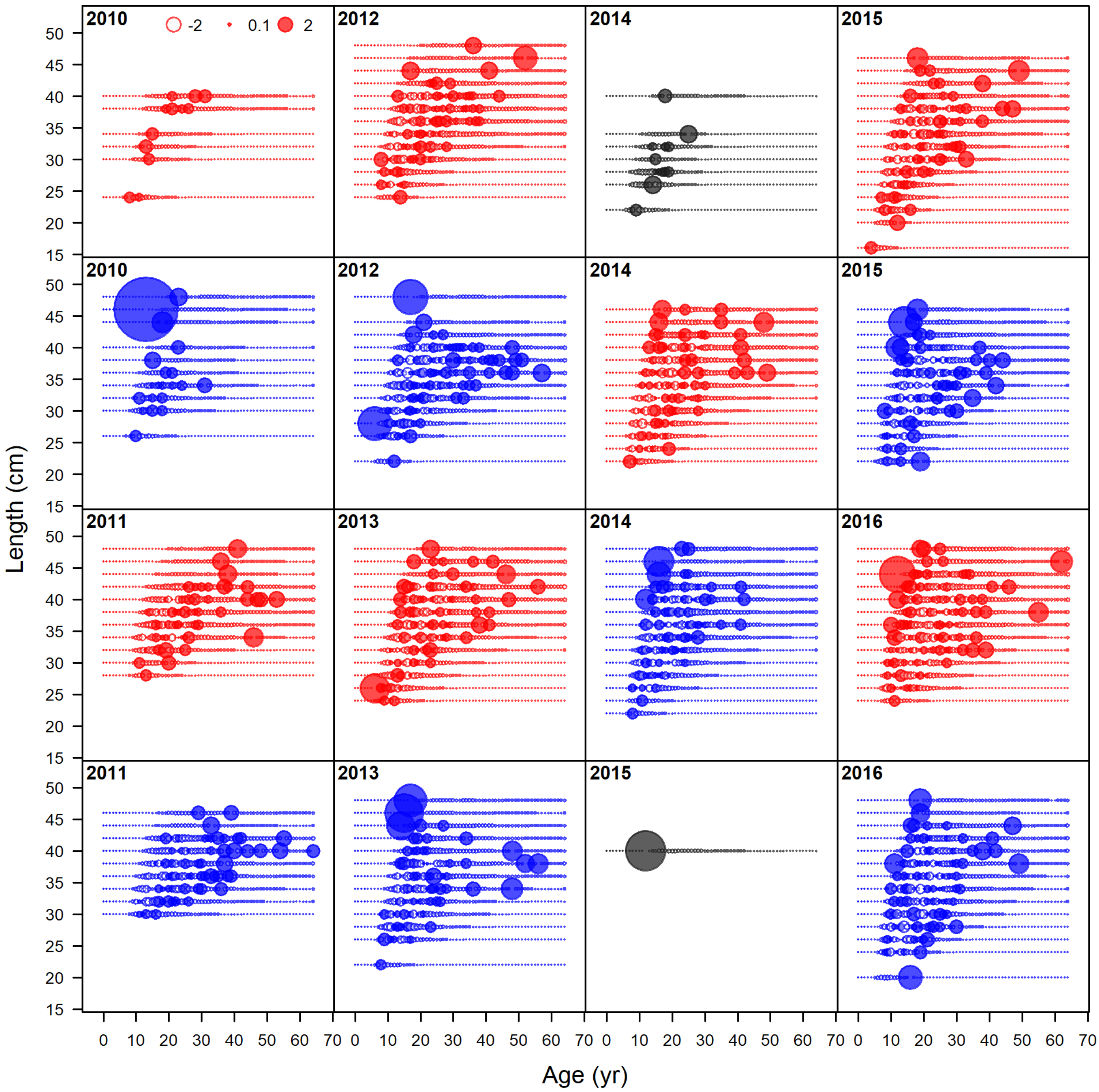

Figure 55. Pearson residuals of conditional age at length data for the trawl fleet. Red dots are females, blue is males and grey is unknown sex.

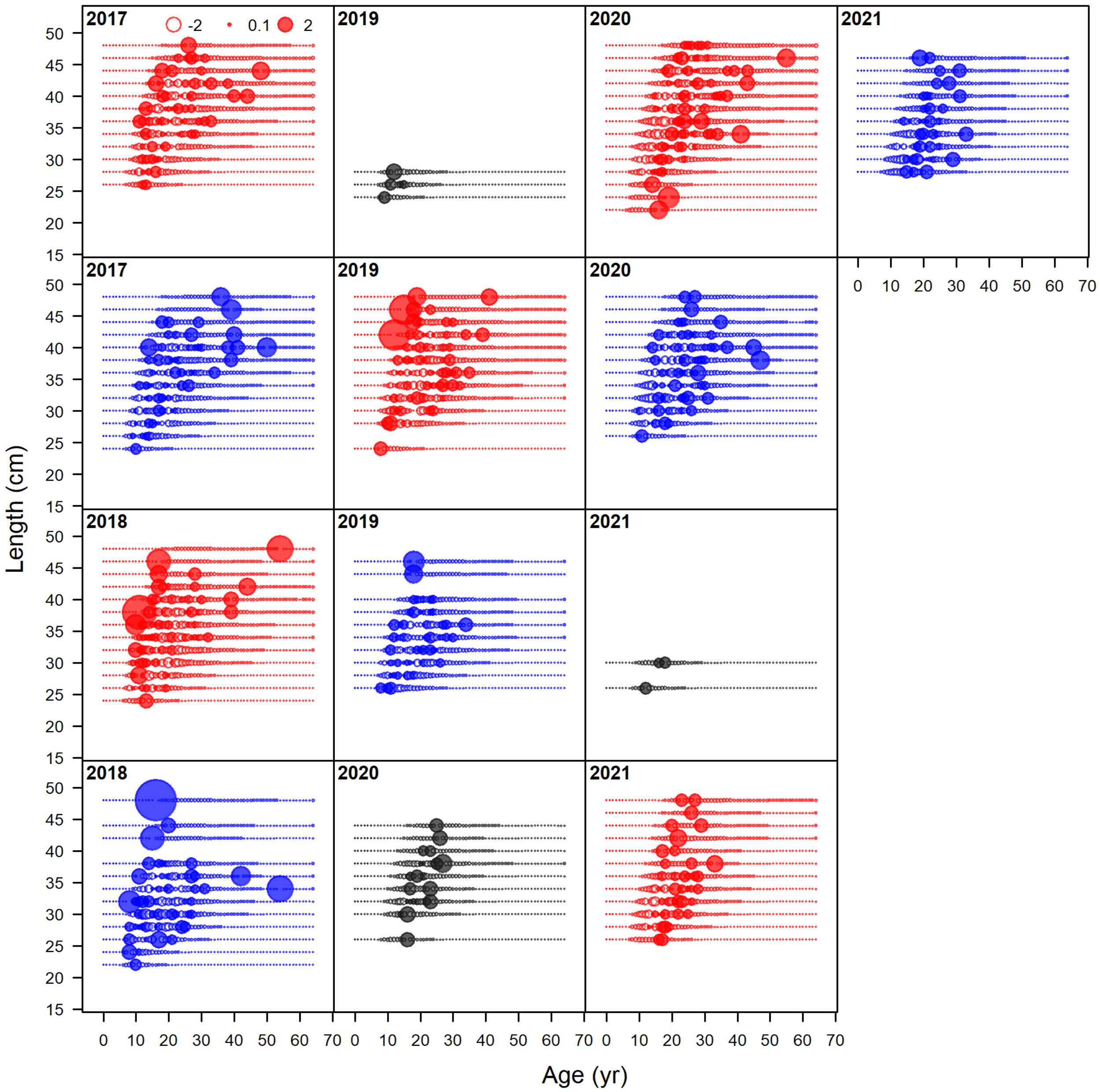

Figure 56. Pearson residuals of conditional age at length data for the trawl fleet. Red dots are females, blue is males and grey is unknown sex.

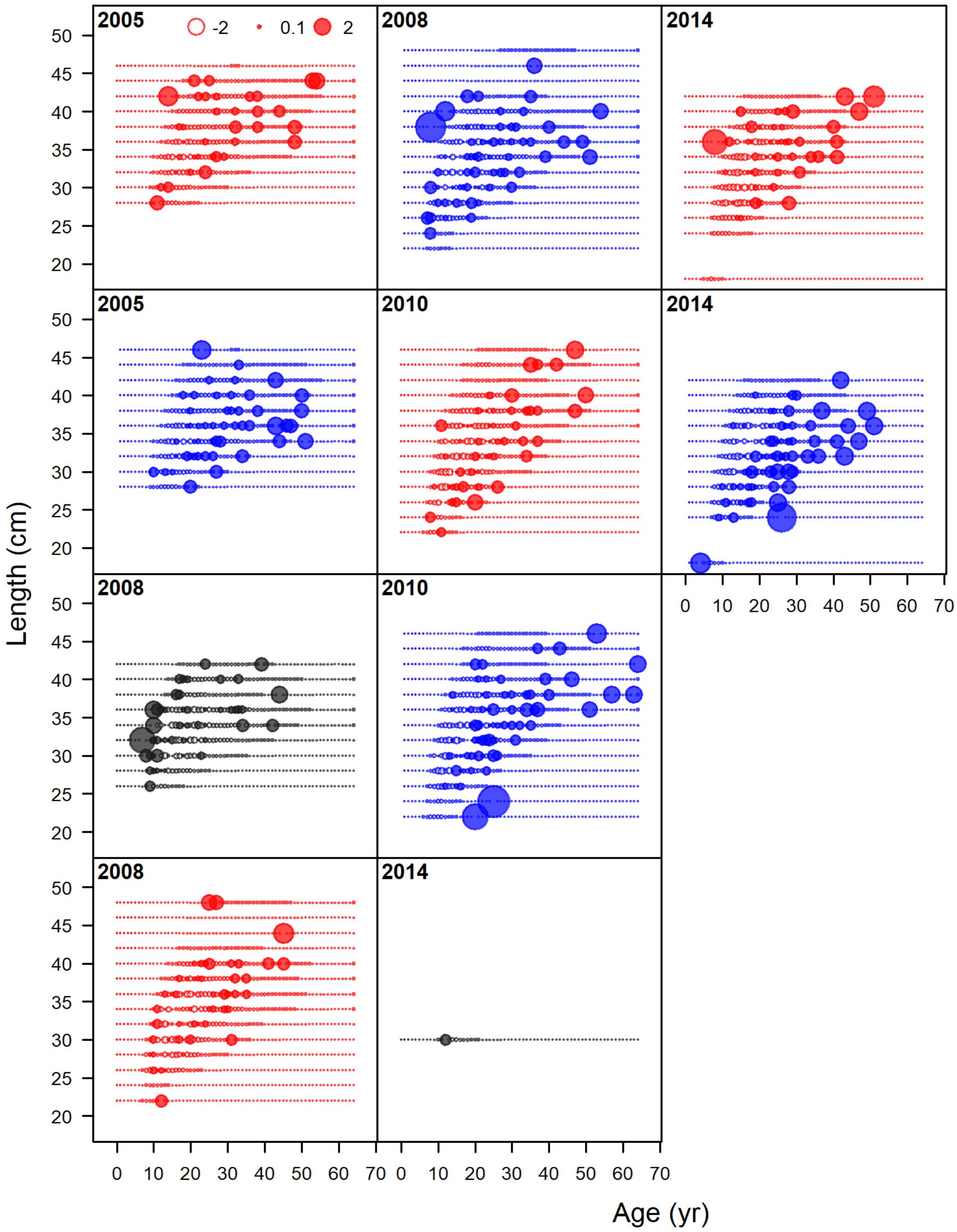

Figure 57. Pearson residuals of conditional age at length data for the GAB-FIS fleet. Red dots are females, blue is males and grey is unknown sex.

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